Development of a Framework for Configuring Fractal Supply Networks and Logistics Capabilities

RAMIN BAHADORI

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Preface

This thesis is presented as part of my requirements for the award of the degree of Doctor of Philosophy from Sheffield Hallam University in the UK. It reports on the research work carried out by the author under the supervision of Professor Sameh Saad in the Faculty of Arts, Computing, Engineering and Sciences at Sheffield Hallam University between May 2014 and May 2018.

The oral examination of the thesis was conducted by Professor Terrence Perera and Professor Andrew Thomas on 23 May 2018.

Candidate's declaration of originality:

This thesis is my own work and obtains no material which has been accepted for the award of any other degree or diploma in any university and, to the best of my knowledge and belief, it contains no material previously used by any other person except where due acknowledgement has been made.

Ramin Bahadori

May 2018

Acknowledgements

I have received invaluable support, encouragement, and guidance from many people during the lengthy period of preparing this thesis. The enthusiasm of colleagues, family, and friends towards my research was a vital source of motivation on those moments when frustration and discontent threatened the progress of this project. I would like to express my gratitude for everybody who has supported me during this momentous phase in my life. I would have never have been able to do this without you.

The support and guidance of my project supervisor Prof. Sameh Saad have been key to success in completing this thesis. His critical and constructive advice throughout the project has been significant to the progress and quality of this research. I would like to thank him for the many opportunities he has offered me to improve my academic record in terms of publications, attending international academic conferences and working in the academic area as an Associate Lecturer. Furthermore, I express my gratitude to the Sheffield Hallam university staff for their cooperation.

Finally, I would like to thank my entire family for their encouragement and support. I would, especially, like to thank my parents, who will be even more proud of my new academic title than I will. For their love, encouragement, and support, I dedicate this thesis to them.

Abstract

The contemporary, dynamic marketplace requires a flexible supply network capable of achieving an effective and efficient logistics operation in order to provide a high level of logistical service and customer satisfaction. A fractal supply network is a reconfigurable supply network which has the ability to present many different problem-solving methods under the terms of the various situations. It has been only proposed and studied recently in the academic literature. However, when the overall number of research works available on this topic is taken into consideration, more work is still needed to, holistically, cover some of the related issues. Therefore, this research presents a framework for configuring/reconfiguring a fractal supply network and its logistical capabilities, with the aim to provide a systematic approach which enables practitioners to measure and optimise the logistics capabilities within the network.

Configuration/reconfiguration is started by developing conceptual models based on changes in the environments with respect to the capabilities of the fractal supply network. Conceptual models for measurement or optimisation problems are developed. A multi-criteria decision-making model is, then, developed to prioritise the logistics capability in the fractal supply network where also questionnaire is used. Quantitative models and simulations with regards to the selected problems are developed and tested hypothetically. A simulation is used for verification and validation. Experimental factorial design and statistical techniques are used to generate and analyse the results.

The research results proved that the proposed framework and developed models in this thesis provide systematic methods through which practitioners should be able to specify high-priority logistics capabilities for further investment planning, introducing a unique dynamic sustainability control system and an inventory control system to increase both collaboration and integration and improve the process of sharing information across the network, which have proven to be a problematic area for industrialists and provides a foundation for further research development.

Publication

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Nomenclature

	Chapter Three
CI	Consistency index
λmax	Maximal eigenvalue
n	Dimension of the square matrix
CR	Consistency Ratio
RI	Random Consistency Index
l	The lower bound of the triangular fuzzy set
m	The mean bound of the triangular fuzzy set
u	The upper bound of the triangular fuzzy set
i	The row number
j	The column number
S_i	The synthetic extent value
$\boldsymbol{M_{gi}^{j}}$	The triangular fuzzy numbers of the pairwise comparison matrix
$d^{'}(A_i)$	The weights of criteria, sub-criteria and possible alternatives
$W^{'}$	The weight of the vector
W	The normalised weight of vectors
	Chapter Four
X	Individual weight of each judgment
L	Approximate amount of maximal eigenvalue (λmax)
n	Sample size (number of judgment)
GM_R	Geometric mean of each matrix's row
A	Comparison matrix
X	Priorities vector
λmax	Maximal eigenvalue
AX_i	The vector which is obtained by multiplying the comparison matrix (A) on Priorities vector (X)
G_{SG}	Global priorities of lower sub criteria with respect to the main goal
W_k	Local weight of main criteria k.
W_i	Local weight of sub-criteria i.
W_{ij}	Local weight of lower sub criteria with respect to the sub-criteria i.
G_{SM}	Global priorities of lower sub criteria with respect to the main criteria
	Chapter Five
V	Sets of nodes
A	Sets of edges
K	Number of available vehicles
Q_k	Capacity of k^{th} vehicle ($k \in K$).
D_i	Customers demand ($i \in V$).
d_{ij}	Length of edge between the nodes i and j $(i,j) \in A$ and $d_{ij} = d_{ji}$
M_{sk}	Minimum shipment weight that must be on the k^{th} vehicle in length of each route during its service
C_{ijk}	CO_2 emission of moving k^{th} vehicle ($k \in K$) between the nodes i and j
T_{wk}	Tare weight of k^{th} vehicle
W_{ijk}	Weight of shipments on board of k^{th} vehicle between the nodes i and j
R_{Ck}	CO_2 emission rate of k^{th} vehicle
y_{ik}	The quantity of the demand of i^{th} customer which is delivered by the k^{th} vehicle.
T_C	Total transportation cost
A_C	Average transportation cost per km
$T_{\boldsymbol{t}}$	Total transportation time route

F_{vk}	Fleet velocity (km/h) of vehicle k
TNV	Total number of required vehicles

Chapter Six

μ_{NZ}	Non-zero demand mean
σ_{NZ}	Non-zero demand standard division
p	Inter-demand interval means
$D\ max$	Max non-zero demand
CV^2_{NZ}	Squared coefficient variation of non- zero demand
N_{NZ}	Non-zero demand count
Di	Aggregated demand size
σ_d	Daily Demand Std Dev
SS	Safety stock
σ_{dLT}	Standard division of demand during the lead time
LT	Lead time
Z	Service level
ROP	Reorder point
μ_{dLT}	Demand mean during the lead time
d_D	Daily demand
σ_{LT}	Standard deviation of lead time in days
μ_{LT}	Average lead time
TDj	Total demand of component/product j
j	Index number of different component/product
DBR	Days between replenishment
RCS	Replenishment cycle stock
T	Period time
q	flow quantity per period,
T	Period time
IHC	Inventory holding cost
$T_{(CI)}$	Total inventory,
$P_{(v)}$	Product value
$I_{(cc)\%}$	Inventory carrying cost percentage
$IT_{(CI)}$	In-transit inventory,
t	Transportation time
NOS	Numbers of shipment
RQ	Replenishment quantity
T_{td}	Total travel distance
td	Travel distance
$T_{(c)}$	Transportation cost
$A_{(c)}$	Average transportation cost per mile
V	Component or product value

Chapter One - Introduction

This chapter is divided into the four sections. The first section presents an introduction to the supply chain management, the second section deals with the historical academic background of fractal and logistics capabilities within supply chain and manufacturing, the thesis aim, the objectives and the list of research questions are provided, while the fourth section indicates the outline of the research work.

1.1. Introduction to the supply chain management

In the 60's and 70's, organisations tried to enhance their competitive advantages using standardisation and improvement in their internal processes to produce high-quality products at the lowest cost. At that time, having strong engineering and design as well as integrated manufacturing operations were the prevailing principles for achieving the more market share. Therefore, the organisation's efficiency received more attention.

In the 80s, diversity in the expected patterns of customers was increased. Thus, flexibility in production lines and the development of the new products were increased to meet customer needs.

In the 90s, along with improvements in manufacturing processes and using reengineering patterns, many industry executives found that internal processes improvement and operational flexibility are not enough for continuing presence in the market. Suppliers should also involve for producing materials with the best quality and the lowest cost. Product distributors should also have a close relationship with manufacturers' market development policies. Thus, the supply chain concept was born.

In today's global marketplace, companies are not able to work independently with a unique brand. Due to the complexity of goods and services, it is very hard for companies to produce a product or provide a service without assistance and cooperation with other companies. Moreover, with today competitiveness in the global business environment and improvements in manufacturing technology, traditional production management methods have lost their effectiveness due to a lack of integrated improvement in their processes; companies need to create a systematic integration in all production processes from supplier to the final consumer. Supply chain management, as an integrated approach, can meet these requirements to manage the flow of raw materials and final products, information and funds. Supply chain integration allows manufacturers and their suppliers to act together and leads the way for performance improvement throughout the chain (Kannan & Tan, 2002).

Supply chain management encompasses the communication and collaboration among supply chain members. It is also responsible for management of supply and demand between one or several organisations (Clifford Defee & Stank, 2005).

The main purpose of supply chain management is to, continuously, identify improvements to the efficiency of supply chain processes in order to deliver the right product to the right customer in the right quantity, quality, and at the right place, time and cost (Si, Edmond, Dumas, & Chong, 2008).

1.2. Historical background of fractal and logistics capability

1.2.1. Fractal

The fractal concept was entered into supply chain management from the early nineties by Warnecke, (1993); however, the overall number of research papers available on this topic is limited.

Ryu & Jung (2003) defined concepts, architecture, and the major characteristics of the fractal manufacturing systems and modelled the basic fractal unit which consists of five functional modules including an observer, an analyser, a resolver, an organiser, and a reporter. Ryu, Son, & Jung (2003) developed a framework for a company in terms of fractal concept and developed mathematical models for both analysers and resolvers as the main functional modules of each fractal. Saad & Lassila (2004) provided various fractal cell configuration methods for different system design objectives and constraints. Fan & Chen (2008) analysed the self-organisation attributes of the fractal supply chain, developed a self-organising dynamic model and applied them in the enterprise supply chain. He (2010) presented the mathematical model to evaluate the self-similarity characteristic in the fractal supply chain. Shin, Mun, & Jung (2009) proposed a method to facilitate the continuous and quick adaptation of a manufacturing system based on fractal organisation. Oh, Ryu, Moon, Cho, & Jung (2010) developed a framework for collaborative supply chain management based on the fractal concept to analyse a trust model for production planning in the automotive industry. Kleinikkink & Noori (2013) introduced and implemented a model based on the fractal concept to develop and increase manufacturing agility attributes and to quicken responses to uncertainty. Ryu, Moon, Oh, & Jung (2013) developed the fractal Vendor Managed Inventory (fVMI) framework to decrease inventory cost and develop a quick response to the market and compared it with traditional vendor managed inventory (VMI) using simulation.

Saad & Aririguzo (2012) discussed the integrated original equipment manufacturer (OEM) and key suppliers in the fractal environment for a truck assembly plant to facilitate the achievement of flexibility and swift responses to uncertainties in the manufacturing environment. In order to explain the fractal concept in the supply chain and manufacturing their proposed model is introduced in this study as follows:

As shown in figure 1.1, the proposed model consists of eight sub-models include 'body-in-white', 'chassis trim supplier', 'motor engine builder', 'electricals/electronics supplier', 'motor transmission supplier', 'paint supplier/shop', 'OEM (dealership) inspection', and 'exit logic' where each sub-models is defined as a self- similar structure, which is referred to as a fractal. In accordance with the fractal point of view, each fractal is a customer as well as a supplier within the enterprise and is linked to each other based on their inputs and outputs. In this case, the suppliers are incorporated as assemblers, working within the manufacturing facility alongside the OEM's employees. Every fractal unit has or is inherently equipped with fractal-specific characteristics. These include self-similarity, self-organisation, self-optimisation, goal orientation and dynamics (Warnecke, 1993) which are explained in detail in the next chapter. These are congenital attributes of fractals. Furthermore, fractal unites may decompose into sub-fractal where each sub-fractal also can be considered as an independent fractal itself. For instance, in this model (see Figure 1.1) the motor engine builder is next on the assembly line, and it mounts the engine which was pre-built at its sub-fractal. Fractal decomposition to sub-fractals can be continued as far as possible. For example, in this case, decomposition of motor engine builder can be stopped if the engine building is completely arranged to be outsourced to suppliers.

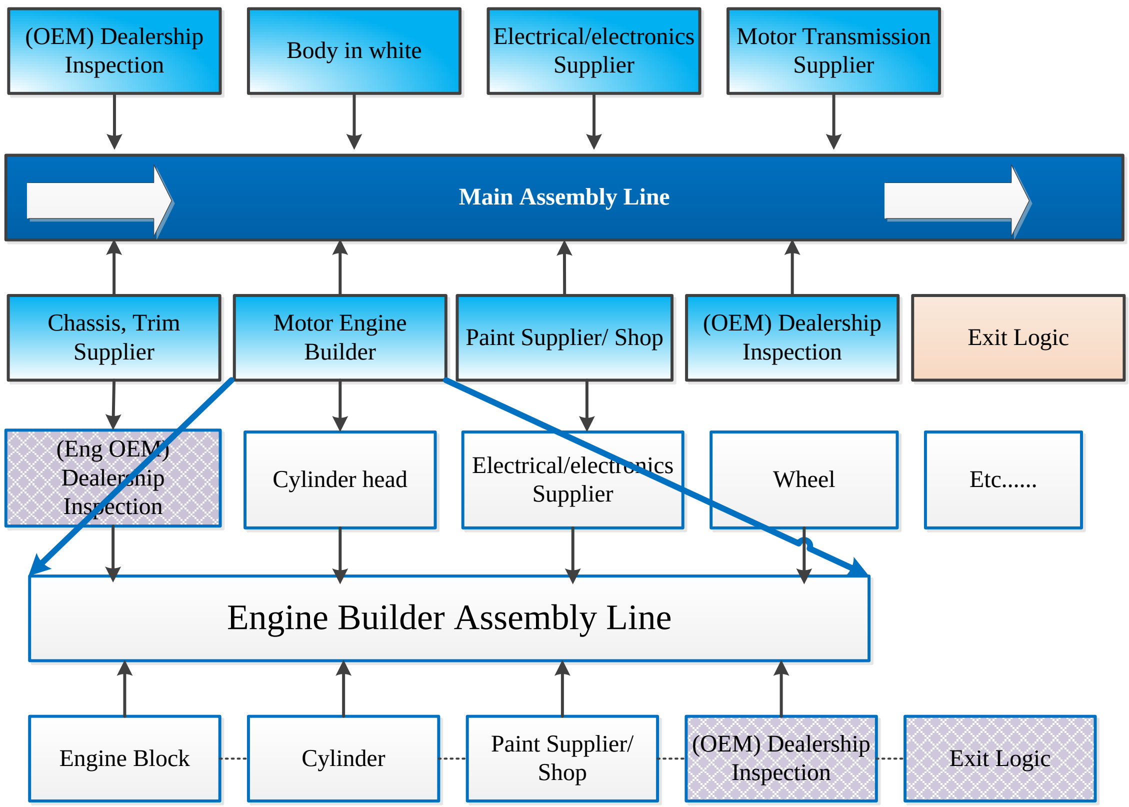


Figure1. 1: Integration of original equipment manufacturer (OEM) and key suppliers in the fractal environment for a truck assembly plant (Saad & Aririguzo, 2012)

1.2.2. Logistics capability

Logistics capabilities, due to its significant role in firm's performance, have become a necessary aspect of supply chain management. Thus, logistics capabilities have been receiving more attention from scholars during the recent decades. Morash, Drsoge & Vickery (1996) studied strategic logistics capabilities, including demand-oriented capabilities and supply-oriented capabilities, and determined the ranking of logistics capabilities in terms of importance to a firm's success by utilising the Stepwise Regression method while, Fawcett, Stanley, & Smith (1997) represented a measure of the firm's logistics performance in five areas including flexibility, cost, quality, time, and innovation by using a regression analysis. They found the time-based capability to be the key factor. Stank & Lackey (1997) defined and measured logistics capabilities in the Mexican maquiladora firms based on a logistics competency model which was produced by Michigan State University. Zhao, Dröge, & Stank (2001) tried to establish relationships among customer-oriented capabilities, information-oriented capabilities and firm performance using the statistical method. Liu & Ma (2005) analysed logistics capabilities, based on supply chain performance in terms of logistics operation capability and potential value-added logistics capability in a transportation enterprise, as a case study using Fuzzy mathematics and AHP methods. Liu & Ma (2006) developed a mathematical presentation in the supply chain to measure logistics capabilities in terms of logistics flux and circulation quantity. Li, Liu, & Guo (2008) explained logistics capabilities in the cluster supply chain based on the logistics service capability and the potential value-added logistics capability and tried to optimise the logistics capabilities using Fuzzy logic and AHP methods. Xu & Wang (2012) defined and analysed logistics capabilities among chain stores in China based on static ability and dynamic ability. Gligor & Holcomb (2012) presented the systematic literature review as well as a conceptual model to show the relationship between logistics capabilities and supply chain agility.

Continuous measurement and optimisation of logistics capabilities will enable firms to provide order winners by adding value to products and services during the different stage of supply chain to gain market shares and enhance firm's performance and customer's satisfaction in contemporary dynamic market. Based on the above background and the literature research outlined in this thesis, it has been proven that from fractal supply network point of view, there is very little in-depth research into this area has been conducted. Hence, the concepts are still relatively abstract in nature with no clear procedure for industrial implementation. This study aims to further develop both conceptual framework and the practical applicability of the selected concepts within supply chain management. Thus, this research tried to develop a framework for configuring fractal supply network for logistics capabilities in order to design, plan, implement and control supply network. The scope of configuring fractal supply network and logistics capabilities is focused on both measurement and optimisation.

1.3. Purpose

The aim of this research work is to develop a framework for configuring/reconfiguring a fractal supply network to provide a systematic approach which enables practitioners to measure and optimise the logistics capabilities within the supply network.

1.3.1. Research objectives

The objectives of this thesis are to:

1. Carry out a comprehensive literature review to establish the current knowledge and practices.
2. Identify the logistics capabilities in a fractal supply network focusing on the input, outputs and the concerned performance measures which should be used to evaluate its success.
3. Develop a conceptual model for the logistics capabilities measurement in a fractal supply network.
4. Develop an AHP/Fuzzy AHP model to represent the logistical capabilities of the conceptual model developed above to enable the consideration of multi-objective optimisation.
5. Validate and verify the proposed logistics capabilities measurement in the fractal supply network.

6. Development of information fractal framework in the supply network and it's logistics capabilities which enable consideration of multi-objective optimisation.

1.3.2. Research questions

The main research questions addressed in this study can be aggregated in two questions, which form the basis of the research:

Question 1: To what extent are the priorities concerning logistics capabilities among fractal supply network members (e.g. Supplier, Supply hub, Manufacture, Distribution centre and Retailer) the same?

Question 2: How does the development of information fractal provide the inventory control system and the dynamic sustainability control system across the supply network? How does it facilitate communication, collaboration, and integration throughout the supply network and enhance the sharing of information within the whole network?

1.4. Outline of the thesis

Chapter 1 introduces the research problem that is to be addressed. It includes the brief introduction to the study area, a review of the academic research background of fractal and logistics capability, the purpose of this study as well, and, also, summarises the research objectives. Later in the chapter, the research questions that form the foundation of the study are formulated. Finally, an outline of the different chapters in the thesis is provided.

Chapter 2 provides an overview of the recent academic research regarding the fractal and logistics capability. The chapter begins with fractal supply network definition and its capabilities. Next, the definition of logistics capability and its classification are included. The chapter is followed by the review of information sharing in supply chains, sustainable supply chain management, Vehicle Routing Problem (VRP), logistics cost, and inventory control strategies in the supply chain. The remainder of the chapter is dedicated to the review of the 'Just-In-Time' inventory system and Vendor Managed Inventory (VMI). The chapter ends with the conclusion and research focus.

Chapter 3 describes the methodologies employed to answer the research questions and develops a framework for configuring fractal supply network and logistics capabilities. First, a brief introduction is presented, then, the major steps of configuring methodology including conceptual understanding, conceptual modelling, decision-making and modelling and analysing are summarised. Later in the chapter, the framework of configuring fractal supply network with a focus on its logistics capabilities is proposed.

Chapter 4 develops a conceptual model of logistics capabilities within a fractal supply network. Logistics capabilities based on fractal supply network are, then, composited. The multi-criteria decision-making model to measure logistics capability in the fractal supply network is developed. Two methodologies are used for pairwise comparison and prioritisation of criteria; classical AHP and fuzzy AHP. Application of AHP and Fuzzy-AHP are explained in detail in separate parts. A comparison between the results from classical AHP and Fuzzy-AHP is provided. Finally, the dynamic sensitivity of Expert Choice is applied to dynamically change the priorities of the main criteria to determine how these changes affect the priorities of the lower sub criteria. Finally, the overall conclusion is given as the last part of this chapter.

Chapter 5 proposes the Information Fractal Structure (IFS) framework based on the fractal concept to improve distribution network sustainability through two variables; Greenfield service constraints and the minimum weight of shipments on board. Supply Chain GURU Software is adapted to implement the Greenfield analysis to identify the optimal number and location for setting up the new facilities. The new green vehicle route problem with split delivery (GSDVRP) is developed and implemented using simulated annealing algorithm which is programmed in MATLAB software. Later in the chapter, the overall conclusion is presented.

Chapter 6 presents two Information Fractal Structure (IFS) frameworks based on the fractal concept and its capabilities in order to optimise inventory and logistics cost across the supply network by combining both centralised and decentralised inventory strategies and facilitating communication and collaboration between the centralised Vendor-Managed-Inventory (VMI) and the Just-In-Time production respectively. The proposed conceptual frameworks and their mathematical models are tested in the hypothetical supply networks and validated using Supply Chain GURU Simulation software. Experimental factorial design and statistical technique (MANOVA) are used to generate and analyse the results followed by the overall conclusion.

Chapter 7 provides the concluding discussions of the research. It includes a discussion of the research findings and its limitations and ends with some suggestion for the future works.

Figure 1.2 displays the main steps of the research process employed in this project.

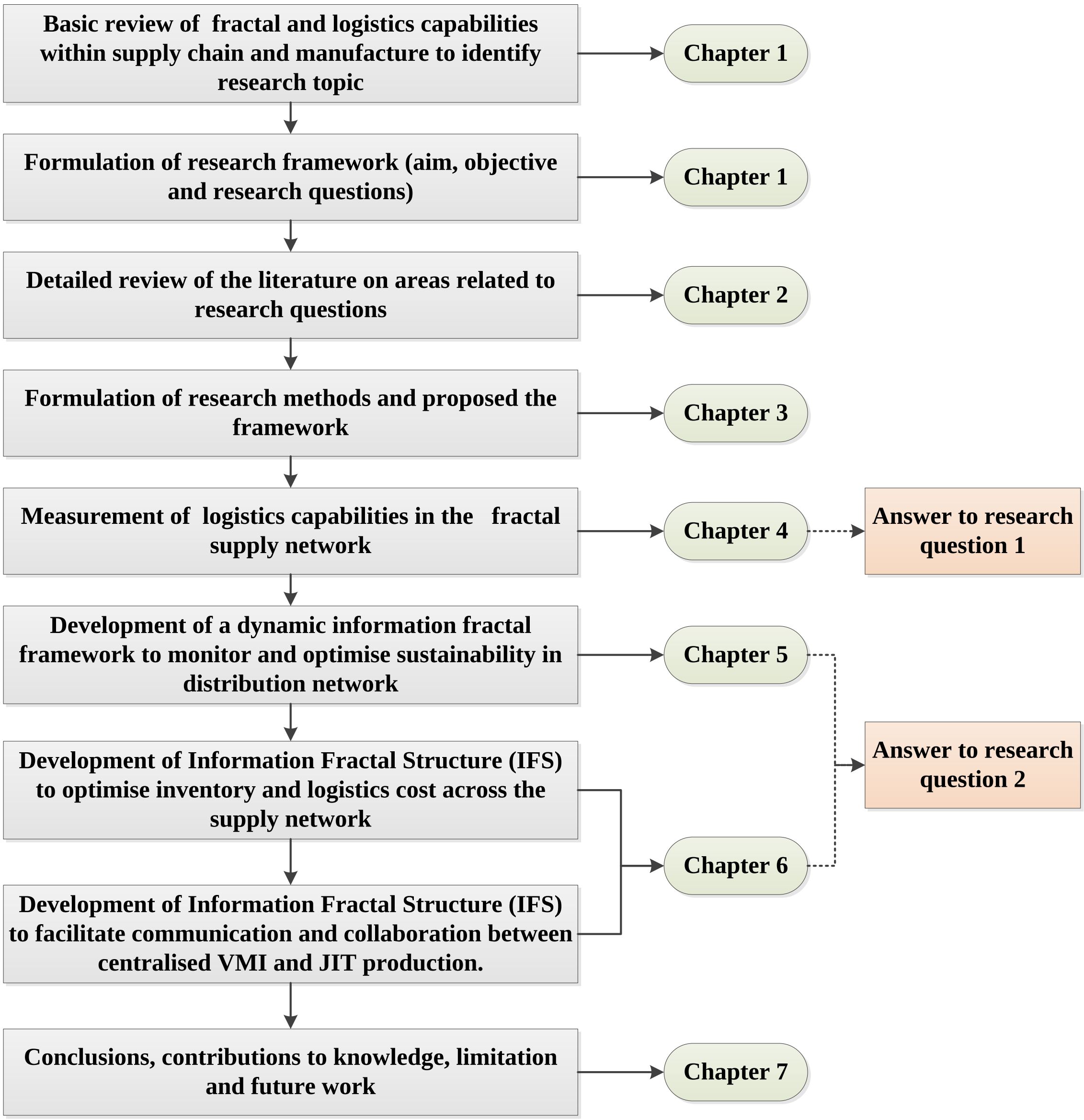


Figure1. 2: Research process

Chapter Two - Literature Review

In this chapter, there is an overview of the academic research on fractal and logistical capability. The chapter begins with a definition of a fractal supply network and an outline of its capabilities followed by a definition of logistical capability and its classification. The chapter progresses to a review of the information sharing in supply chains, sustainable supply chain management, logistics costs, and inventory control strategies in the supply chain. Further in the chapter is a review of the Just-In-Time inventory system and Vendor Managed Inventory. The chapter is ended with a conclusion and the research focus.

2.1. Fractal supply network

2.1.1. Definition

A fractal supply network can be defined as a reconfigurable supply network which can present many different problem-solving methods in various situations (Fan & Chen, 2008). It is a set of self-similar agents by which system's goal can be achieved through cooperation, coordination, and negotiation with others (Ryu & Jung, 2003). The fractal supply network is composed of different fractal units named the Basic Fractal Unit (BFU) (Ryu et al, 2013) which are identical to each other and have the ability to make decisions, use appropriate methods, generate goals and adapt to a dynamically changing environment by themselves. A Basic Fractal Unit (BFU) consists of five functional modules, including an observer, an analyser, a resolver; an organiser and a reporter (see Figure 2.1):

- Observers function as an input gate of each fractal and must monitor, trace and receive data and messages from outer fractals and the environment, and transmit the composite information to the correspondent functions (e.g. Resolver and Analyser) in the fractal. The messages or data from outer fractals can be different in terms of the hierarchical position of the fractal.
- The analyser is one of the main fractal functions which employs an appropriate method to analyse the current fractal situation based on information which is provided by the observer and the predefined criteria then transmits the analysis results to the resolver.
- The resolver function performs the decision-making processes which are based on the information that is provided by the observer and the results from the analyser.
- The organiser function observes, controls and manages the fractal structure to adapt to the continuous changes in the environment.

- The reporter function, as an output gate, has a responsibility to report fractal outputs to the outer fractals.

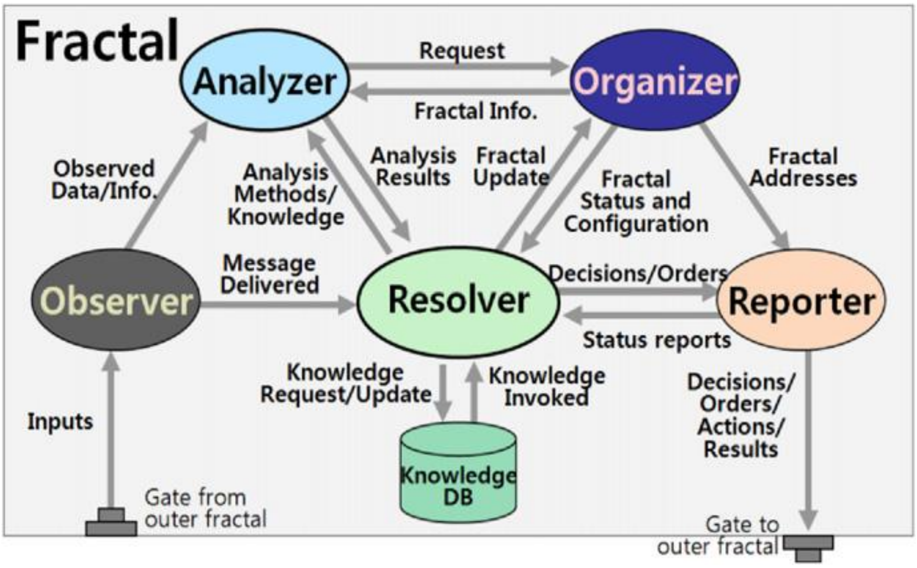


Figure 2. 1: BFU architecture (Ryu et al, 2013)

2.1.2. Fractal supply network capabilities

The fractal supply network attracts many in the industry because of its capabilities such as self-similarity, self-optimisation, self-organisation, goal orientation, and dynamics (Warnecke, 1993).

Self-similarity means each fractal unit is similar to another fractal unit whilst having their own structure (Attar & Kulkarni, 2014). Although, fractal units may have different conditions and internal structures in comparison to one another; they can have the same target in the system. Therefore, in the fractal supply network, fractals are self-similar if they can achieve goals in the system with different internal structures while inputs and outputs are the same (Ryu et al, 2013) as illustrated in Figure 2.2. Higher self-similarity in the supply network can increase the level of information sharing, operation coordination and the degree of integration among the fractal units and decrease the complexity of the system and ensure the supply network is understood and managed clearly (He, 2010).

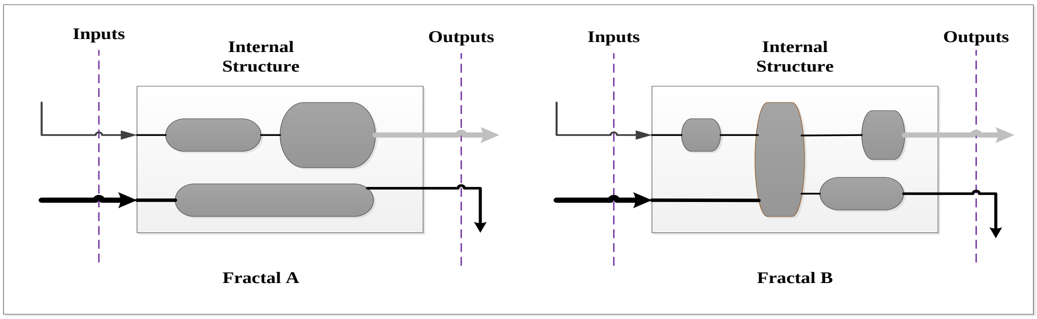


Figure 2. 2: Self-similar fractals with different internal structure (Warnecke, 1993)

Self-optimisation means each fractal unit is an independent unit with the ability to improve its own performance continuously. Fractals choose and use suitable methods to optimise operation and decision-making processes with the coordination of the whole system to achieve the goals (Attar & Kulkarni, 2014; He, 2010; Ryu et al, 2013).

As illustrated in Figure 2.3, self-organisation (dynamic restructuring) refers to the support of the reconfiguration of network connections between fractals and the reorganisation of fractals in the system (Ryu & Jung, 2003). It means each fractal is free to make a decision about the organisation's dimensions which is required for specific performance in regards to environmental parameters and the goals without external intervention (He, 2010; Leitão & Restivo, 1999). In fact, self- organisation is a kind of supply chain organisation which converts irregular conditions into regular conditions without outer monitoring and control to offer products and services to customers constantly (Fan & Chen, 2008).

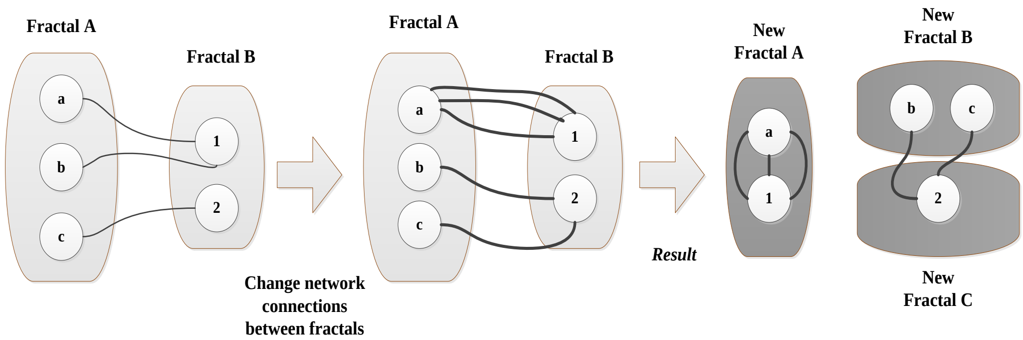


Figure 2. 3: Dynamic restructuring process (Ryu & Jung, 2003)

Goal orientation enables the system goals to be achieved from the goals of individual fractals (Warnecke, 1993). Fractal units perform a goal-formation process to generate their own goals by coordinating processes with the participating fractals and modifying goals if necessary (Ryu & Jung, 2003) (see Figure 2.4).

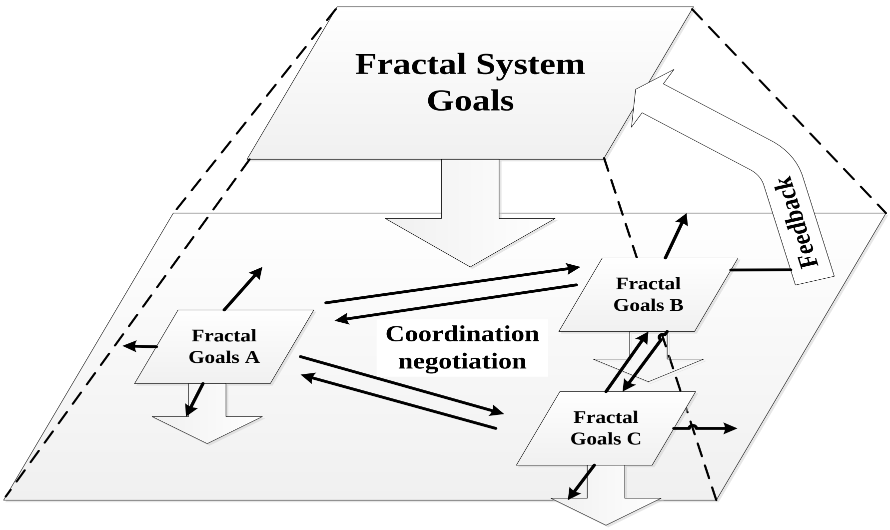


Figure 2. 4: Goal-formation process in the fractal system (Ryu & Jung, 2003)

Dynamics refer to the cooperation and coordination between self-organising fractals which are characterised by a highly individual dynamic and an ability to restructure their processes to meet and adapt to the dynamically changing environment (Ryu & Jung, 2003).

2.2. Logistics capability

2.2.1. Definition

Logistics capabilities require three steps including planning, implementing and controlling with a set of abilities and organisational processes as well as knowledge and skills that allow to add value to the products and services during the different stages of the supply chain, enabling order winners for the firms to win the competition and enhance the firm's performance and customer's satisfaction (Mentzer, Min, & Michelle Bobbitt, 2004; Morash et al., 1996; Stank & Lackey, 1997; Zhao, Dröge, & Stank, 2001).

2.2.2. Logistics capabilities classification

In accordance with the past literature, logistics capabilities can be categorised in a variety of ways (Gligor, & Holcomb, 2012). Global Logistics Research Team & Council of Logistics Management at Michigan State University (1995) identified seventeen logistics capabilities which were classified into four competencies including positioning, integration, agility, and measurement. Morash et al. (1996) categorised logistics capabilities into two major value disciplines; demand-oriented capabilities and supply-oriented capabilities. Mentzer et al. (2004) defined logistics capabilities as firms' competitive advantages in four broad categories including demand-management interface capabilities, supply-management interface capabilities, information-management capabilities, and coordination capabilities. While, Stank, Davis, & Fugate (2005) introduced a comprehensive classification of logistics capabilities in four categories, including customer focus, time management, integration, information exchange, and evaluation. The five main logistics capabilities employed in this study are integration capability, supply-oriented capability, customer demand-oriented capability, information exchange capability and time management and logistics cost capability.

2.2.2.1. Integration

Integration is necessary to achieve the unity of efforts to meet goals in the organisations and, consequently, have a positive relationship with the firm's performance (Stank et al, 2005). Integration, as a key logistics capability, is taken into consideration in much of the literature concerning logistics. Bowersox, Closs, & Stank, (2003) discussed several elements of integration, including cross-functional unification, standardisation, simplification, structural adaptation, and compliance. Kahn & Mentzer (1996) defined inter-departmental integration and relates how such integration may impact logistics' performance including logistics' department performance success and overall company success. They indicated that the level of cross-functional integration is significantly related to new product development performance. Stank, Daugherty, & Ellinger (1999) studied the integration of marketing and logistics functions and claimed that a firm's performance and competitiveness are closely related to its logistics' integration. Williams, Nibbs, Irby, & Finley (1997) emphasised the importance of cross-functional coordination toward integration efficiency. Paulraj & Chen (2007) explored the connection between logistics integration and strategic buyer-supplier relationships regarding the firm's agility performance. Gimenez (2006) analysed both the internal and external integration processes within the Spanish food manufacturers and showed that companies must achieve the highest levels of integration in the logistics-production and logistics-marketing interface before starting any external integration. Themistocleous, Irani, & Love (2004) conducted a case study to investigate the integration of supply chain management systems through enterprise application integration (EAI) technologies to achieve the physical integration of supply chain information systems.

Caputo & Mininno (1996) highlighted the importance of logistics integration into the marketing for better performance of online retailers.

2.2.2.2. Supply-oriented capability

Supply-oriented capability focuses on the internal customers' relationship and, also, the distribution network within the supply network to achieve both market value and the competitive advantage. Selective distribution coverage is one of the supply-oriented capability elements which enables a firm to target selective or exclusive distribution outlets effectively and provides the selected middlemen with higher profits (Mallen, 1971; Morash et al., 1996). Selective distribution can be distinguished in terms of the level of intensity of products distribution. It needs the careful examination to choose the number and types of intermediaries who are active in that particular market through which the product will be offered (Leigh & Gabel, 1992; Urbanska, 2007). Supplier selection, relationship, and involvement are the main aspects of supply-oriented capability helping firms to select and maintain high quality and reliable suppliers (Saad, Aririguzo, & Perera, 2012). As most firms spend a considerable amount of their revenues on purchasing; the supplier selection process has become one of the most important decision-making problems. Selecting the right suppliers significantly reduces the purchasing costs and improves corporate competitiveness (Çebi & Bayraktar, 2003). Moreover, long-term supplier relationships lead to maximising the overall value of the manufacturer and customer satisfaction level, in turn, to a reduction in the product supply risk (Chan, Kumar, Tiwari, Lau, & Choy, 2008), in lead-time, in final product costs and in the potential increase of the product value (Wynstra, Van Weele, & Weggemann, 2001). The next element of supply-oriented capability is reverse logistics which refers to all operations related to the re-use of products and materials in the supply network. Reverse logistics is a systematic process that manages the flow of products/parts from the point of consumption back to the point of manufacture for possible recycling, remanufacturing or disposal (Dowlatshahi, 2005). Effective reverse logistics lead to customer satisfaction improvement, decreases resource investment levels and reduces storage and distribution costs (Du & Evans, 2008). In addition, operating across different businesses and different regions enables firms to provide widespread and intensive distribution coverage to create a competitive advantage (Morash et al., 1996).

2.2.2.3. Customer demand-oriented capability

Customer demand-oriented capability is another key logistics capability which provides a competitive advantage for the firms by placing the focus on the product or the service differentiation and service enhancement to maximise the external customer satisfaction with unique, value-added activities (Mentzer et al., 2004; Morash et al., 1996; Stank et al., 2005). Customer service, as the output of the logistics system, is a vital area in logistics management that provides a differentiating element for achieving competitive advantages in the marketplace (Huiskonen & Pirttilä, 1998; Leuschner, Charvet, & Rogers, 2013). Output improvement and the reconfiguration of products/services for the next lifecycle can be created in terms of quantity, time, place and quality which, consequently, have a positive effect on customer satisfaction and the firm's revenues (Ballou, 2006; Novack, 1987; Van der Meulen & Spijkerman, 1985). The sustainable, continued success of the firm comes from its ability to meet product/service needs of each major customer or customer segment. Thus, the use of appropriate customer segmentation strategies, in terms of logistics requirements, is an important aspect of customer demand-oriented capabilities (Bowersox et al, 1999; Zhao et al, 2001).

2.2.2.4. Information exchange capability

Information exchange capability is recognised as another logistic capability which has positive correlation with improving firms’ performance and enabling firms to achieve a distinct, competitive differentiation in the marketplace by acquiring, analysing, storing, and distributing information both internally and externally through the supply network (Bowersox et al, 1999; Zhao et al, 2001). Computer-based information systems are playing a crucial role in the development of logistics as a management discipline (Gustin, Daugherty, & Stank, 1995). Information systems development (Sandkuhl & Kirikova, 2011), the development of appropriate information technology, information sharing, and connectivity (Bowersox et al., 1999) are the major elements of the capabilities of information exchange.

2.2.2.5. Time management and logistics cost capability

Time management and logistics cost capability enable firms to manage both time and cost, effectively, to eliminate wasted capital and inventory, minimising logistics cost and increasing responsiveness within the supply network (Daugherty & Pittman, 1995; McGinnis & Kohn, 1993; Mentzer, Min, & Zacharia, 2000).

Logistics postponement and speculation strategies are key fundamentals of time management; logistics cost capability offers opportunities to achieve the delivery of products in a timely and cost-effective manner (Pagh & Cooper, 1998). Logistics postponement, as a combination of time and place postponement, involves delaying the forward movement of goods as long as possible and storing goods at central locations within the supply chain until customer orders are received (Stank et al., 2005; Wong, Potter, & Naim, 2011). A successful example of logistics postponement is Ford’s European Distribution Centre in which spare parts are distributed to dealers and garages within 24 to 48 hours (Hsuan Mikkola & Skjøtt-Larsen, 2004). In accordance with logistics speculation, finished products are shipped as inventory to the location closer to the customer (decentralized inventory), while the manufacturer waits for customer orders (Lin & Wu, 2013). Inventory cost, low total cost distribution, and responsiveness to customer demand fluctuations are other essentials of time management and logistics cost capability (Daugherty & Pittman, 1995; McGinnis & Kohn, 1990; Morash et al., 1996).

Unlike previous research, the measurement of logistics capabilities from the perspective of fractal supply network, the majority of logistics categories will be considered in this study to answer the first research question.

2.3. Information sharing in supply chain

In the previous literature, information sharing has been defined in various ways. For instance, Simatupang & Sridharan (2004) expressed that information sharing is the timely capturing and disseminating of relevant information in order to enable decision makers to plan and control the supply chain operations. Kim & Umanath (2005) defined information sharing within the supply chain as a regular flow of information from one supply chain member to other members.

Information sharing, the most basic form of coordination in supply chain, has a positive relationship with improving firm performance and enables firms to achieve distinct competitive differentiation in the marketplace by acquiring, analysing, storing, and distributing information, both internally and externally, through a supply network (Bowersox et al, 1999; Zhao et al, 2001). Moreover, information sharing as an integrating action can be applied to both internal and external integration in the supply chain (Lotfi, Mukhtar, Sahran & Zadeh, 2013). Internal integration refers to the coordination and collaboration of functional areas within a company whilst, external integration points synchronise with key supply chain members (Chang, Ellinger, Kim, & Franke, 2016). This research focuses on information sharing among supply chain members (external integration) and information sharing among the components of each member during the inven4tory optimisation process (internal integration). Of all areas of potential improvement in supply chain management, information sharing is one of the greatest interests. When a company uses information from other partners in the supply chain, the negative effects of uncertainty in the modern business environment such as high inventory levels, wrong demand forecasts, and defective orders can be reduced. Many studies have analysed the value of sharing information in supply chains. Gavirneni, Kapuscinski, & Tayur (1999) investigated and analysed the benefits of information sharing in a two-echelon supply chain by considering one supplier and one retailer with several levels of information sharing. In the first level, when there is no demand for information flow to the supplier except historical data. In the second level, when the supplier has information regarding the type of inventory control policy and demand distribution of the retailer and, in the third level, when the supplier has full access to the retailer's daily inventory position. Lau, Huang, & Mak (2004) analysed the effect of information sharing on inventory replenishment in three-stage supply chains with one manufacturer; its distribution centres and retailers. They investigated four types of information sharing; sharing order information among nodes; demand, safety factors and inventory information sharing from retailers to their distribution centres; sharing order information of retailers with manufacturers from distribution centres; sharing order information from retailers to distribution centres and from distribution centres to manufacturers. Lee, So, & Tang (2000) developed a simple two-stage supply chain with manufacturer and retailer and indicated how the manufacturer can achieve benefits from information sharing by decreasing the inventory and saving costs directly. Yu, Yan, & Edwin Cheng (2001) explained information sharing benefits in the decentralised supply chain with a single manufacturer and single retailer by implementing three scenarios. In the first scenario, there was no information sharing between manufacturer and retailer. Each of them made decisions about their inventory based on their own forecasting. In the second scenario, the manufacturer used both customer demand information and retailer order information for inventory decision-making. In the third scenario, the manufacturer took the initiative to make decisions for both its inventory and retailer inventory replenishment based on customers' demand. Cachon & Fisher (2000) compared an information policy without/with information sharing by considering a single supplier and multiple retailers and fixed random customer demand to determine the value of demand and inventory information sharing to reduce the supply chain cost. Moinzadeh (2002) considered a supply chain with one supplier and multiple retailers dealing with a single product and assumed that the supplier has online access to the retailers' demand and inventory information. He found that information sharing in systems can be most valuable when compared to systems which do not use information sharing where there is a long lead time from suppliers, the number of retailers is not very large, order quantities are medium and there is little differentiation between retailers and suppliers in terms of the ratio of the unit holding cost. Chen, Yang, & Yen (2007) investigated the effect of information visibility on the performance of multi-echelon supply chains which includes suppliers, manufacturers, distributors, and retailers. They developed simulation models to analyse four performance measures (total cost, order fulfil rate, customer service and order cycle time) in several scenarios.

Depending on the organisation's needs, a wide range of information such as information related to market, product, design, process, production, pricing, planning, inventory, logistics, demand forecast, customer orders, production scheduling, distribution operations, technological know-how, production methods, and sales forecast could be shared with supply chain members (Omar, Ramayah, Lo, Sang, & Siron, 2010). Seidmann & Sundararajan (1997) classified information sharing into four levels based on the impact of the shared information on each participating party. The first level of information sharing involves the sharing of transaction data (e.g. order quantities and price) and each party acts independently to improve its own efficiency. The second level involves the sharing of some operational information (e.g. level of inventory). Vendor Managed Inventory (VMI) is a good example of this level of information sharing which supplier has the responsibility to manage customer inventory. The sharing of strategic information (e.g. sharing point-of-sales data) is the next level. While this information has minimum values for the owner of information but has strategic value when used by another party. The last level contains sharing information which has both strategic and competitive value when used by another party (see Figure 2.5). Table 2.1 presents a variety of information sharing types which are emphasised in the past studies.

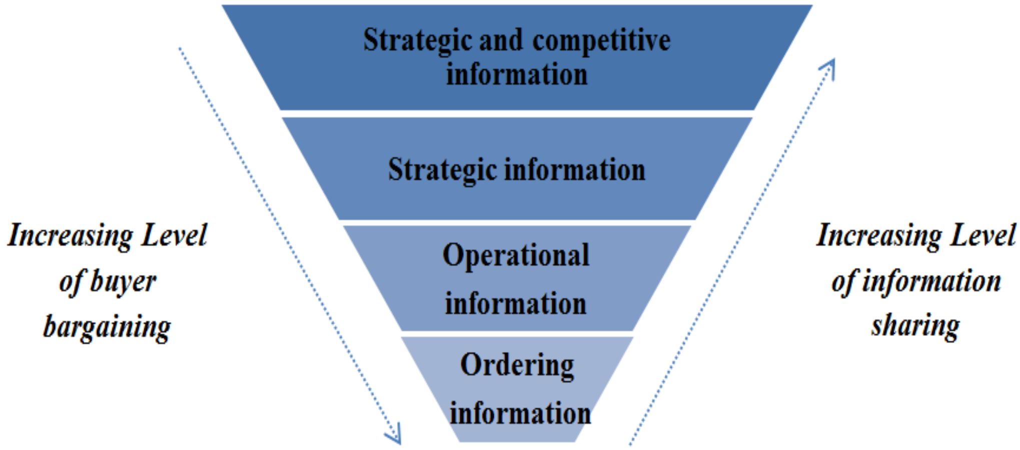


Figure 2. 5: Model of information sharing (Seidmann & Sundararajan, 1997)

Table 2. 1: Supply chain information sharing types

Authors	Information sharing types
(Mason-Jones & Towill, 1997)	Information planning (e.g. product/material demand and the number of customer orders), control information, operational information
(Handfield & Nichols, 2002)	Customer information (e.g. forecast information, sale history, and point of sale), Supplier information (e.g. product lead time, capacity and production scheduling, inventory level and cost information)
(Lee & Whang, 2000)	Inventory level, sale data, order status, sale forecast, production/ delivery schedule
(Chopra & Meindl, 2007)	Manufacturer information, distributer information, retailer information, demand information.
(Barut, Faisst, & Kanet, 2002)	demands information, capacity information, inventory information, scheduling information
(Moberg, Cutler, Gross, & Speh, 2002)	Operational information (e.g. sale, order and inventory activities), strategic information (marketing, logistics, and other business strategies)
(Huang, Lau, & Mak, 2003)	Production information (e.g. product, process, resource, inventory, order, and planning)
(Eisman, 2008)	Business strategies and operations information
(Omar, Ramayah, Lo, Sang, & Siron, 2010b)	Operational and strategic information

The above literature review revealed that in general, there are two main research approaches on information sharing. The first is focused on the value of information sharing from a quantitative perspective. These studies identify and prove the value of information sharing for managers and discuss how to measure the related factors that may affect on its value. The second approach is related to the information sharing requirements such as technologies and other factors which are needed to ensure timely and accurate sharing of information with the aim of responding to the managerial needs using a wide range of quantitative-qualitative techniques. By reviewing the literature, the absence of conceptual modelling for information sharing in the supply chain is well understood and has been one of the main drivers of this research.

2.4. Sustainable Supply Chain Management

Sustainable supply chain can be defined as integration of environmental, social and economic concerns in various policies of the organisation, such as purchasing, design, manufacturing, distribution and logistics, with emphasis on the activities of managers in the context of (Taticchi, Tonelli & Pasqualino, 2013):

(1) the requirement to reduce the negative impacts of social and environmental issues.

(2) the consideration of all steps along the whole value chain for each product.

(3) a multidisciplinary perspective that covers the entire product lifecycle.

Increasing environmental concerns about the effects of supply chain in the natural environment leads to increase pressure from various stakeholders to improve the sustainability performance of the product's life cycle from the point of origin to the final consumer (Ilbery & Maye, 2005). The supply chain has many impacts on the environment in terms of waste, packaging, last miles, greenhouse gas (GHG) emissions, energy consumption, and etc. (Yakovleva, Sarkis, & Sloan, 2011). The energy consumed by supply chain, due to the use of various storage and processing facilities, is a key issue (Zanoni & Zavanella, 2011). Nonetheless, waste management needs to be also considered, especially in countries which have made little progress on waste management and recycling (Jones, Comfort, & Hillier, 2008). GHG emissions are one of the main environmental indicators with key impacts from shipping and logistics operations through supply chain (Oglethorpe, 2010).

Social is recognised as another sustainability aspect in the operations and supply chain which includes all management practices to develop the human potential and protects them from harm (Awaysheh, & Klassen, 2010). It refers to a commitment to achieving social benefits, real and legitimate participation, and accepting different ethical approaches (Spence & Bourlakis, 2009).

Economic sustainability as an important factor in any business is also taken into consideration in much of the literature concerning operations management (Pham & Thomas, 2012). Reducing cost has been already a major focus in many businesses, however, economic crises and globalisation are increasing the importance of achieving the lowest cost in almost all supply chains (Soysal, Bloemhof-Ruwaard, Meuwissen, & der Vorst, 2012). Transaction cost, quality, price, promotion, flexibility, delivery, R&D, financial performance (e.g. profitability, sales growth, and market share) and branding are the common factors that govern the economic sustainability of supply chain (Kristal, Huang, & Roth, 2010).

Many researchers believe that a balance achieved between environmental and economic dimensions play an important role through decision-making process for achieving sustainability in supply chain (Kuik, Nagalingam, & Amer, 2011) which many of the changes in cost and competition in supply chain can be achieved with environmental sustainability (Christopher, Khan, & Yun, 2011). Hence, the focus of this research study is the environmental impact through distribution network where known as one of the major sources of environmental concern within supply chains.

2.4.1 Green Vehicle Routing Problem (GVRP)

The Vehicle Routing Problem (VRP) is part of a series of problems that are associated with determining a set of routes in which each vehicle starts moving from a certain warehouse, serving a set of specified customers, and returning to the same warehouse. This problem was first introduced by Dantzig & Ramser (1959) and solved by mathematical methods. In the form of the graph theory, it is defined as, Suppose that G (V, A) represents the graph in which $V= \{0, 1, \ldots, n\}$ demonstrates $n+1$ nodes; node 0 corresponds to the depot with zero demand where vehicles are located there and other nodes $\{1, \ldots, n\}$ corresponds to n customers with non-negative demand. $A= \{(i, j) \mid i, j\} \in$ V and $i \neq j\}$ demonstrates sets of edges (i, j) of each route which are in graph G.

Transportation has irreparable effects on the environment; consumption of resources, toxic effects on ecosystems and humans, noise and emissions of greenhouse gases (GHG) and pollutants are examples of these risks. Apart from these negative effects, emissions of greenhouse gases and carbon dioxide (CO_2) are directly linked to the health of the community and, indirectly, to the destruction of the ozone layer (Bektaş & Laporte, 2011). However, most research in this area has taken into account economic goals by minimising the distance, the time required or the number of vehicles needed and has neglected attention to environmental goals. Hence, The Green Vehicle Routing Problem (GVRP) has received the attention by scholars since 2006 and two categories, including Green-VRP (G-VRP) and Pollution-Routing Problem (PRP), are predominantly focused on reducing the energy consumption and CO_2 emissions respectively (Lin, Choy, Ho, Chung, & Lam, 2014).

In terms of G-VRP, the following studies can be noted. Kara, Kara & Yetis (2007) modelled the Energy-Minimizing Vehicle Routing Problem (EMVRP) like the capacitated VRP (CVRP) with a new cost objective function based on the total load and Arc length. However, they claimed that this model minimises the total energy requirement and ultimately the total fuel consumption the details of the formulation of fuel consumption are not provided. Peng & Wang (2009) modelled the VRP based on fuel consumption by considering just load of the vehicle. In their objective function, minimisation of both vehicle travel distance and the fuel consumption are targeted. They suggested that to have lower fuel consumption, serving the customers with high demand must be prioritised rather than customers with lower demand. A formulation of fuel consumption is done by (Xiao, Zhao, Kaku & Xu, 2012). They added a Fuel Consumption Rate (FCR) as a load-dependent function into CVRP model and developed CVRP model with the objective of minimising fuel consumption. In their work, they investigated both the distance travelled and the truckload to determine the fuel costs. Kuo (2010) noted that, in addition to the travel distances and load weights, also transportation speed should be added to the fuel consumption calculation model in time-dependent VRP. Norouzi, Sadegh-Amalnick, & Tavakkoli-Moghaddam (2017) developed a new mathematical model based on time-dependent vehicle routing problem to reduce fuel consumption by using the Particle Swarm Optimization (PSO) algorithm.

Among the studies that paid attention to PRP, Maden, Eglese & Black (2010) considered the VRP problem with a time windows constraint and proposed and implemented the heuristic algorithm in a case study within the UK which received a saving of about 7% in CO_2 emission. Palmer (2007) presented an integrated model for routing and carbon dioxide emissions. He considered the role of speed in reducing carbon dioxide emissions in various congestion scenarios with window time and reduction of 5% in CO_2 emissions was achieved. However, the effect of the weight of the load was not considered in this scenario. Bektaş & Laporte (2011) developed a comprehensive objective function of carbon emissions, driver's cost and fuel consumption within the PRP model, with or without time windows, while they considered a minimum speed of 40 km/h, an assumption that does not consider congestion situations. In continuing this research, Demir, Bektaş & Laporte (2012) investigated the optimal driving speed and showed that a reduction in CO_2 emissions could occur by changing the speed within a network.

2.5. Logistics cost

Logistics processes affect the customer satisfaction, product value, benefits and operating costs and it is important in two aspects; the essential and the costly (Aronsson, Ekdahl, & Oskarsson, 2003). Enhancing delivery performance and reducing those costs which are caused by activities related to logistics of a company or a supply chain are aims of logistics management (Borgqvist & Hultkrantz, 2005).

The concept of total cost of logistics is very important because this criterion can be a good basis for cost-cutting analysis. Effective logistics cost reduction is very dependent on an integrated and systematic approach, while the focus on minimising the cost of each area separately may be offset by increased costs in other areas (Stock & Lambert, 2001). Total logistics costs are often provided as a large part of total sales revenue (Min, Song, & Wang, 2009). The definitions of logistics costs can vary in different companies. In a large number of companies, logistics costs reports are different even with similar business and there are different items charged at their own expense. However, the main activities of the operational logistics including transportation, handling, storage and maintenance of inventory make up the key logistics costs (Gudehus & Kotzab, 2009).

High-interest rates, lack of competitive markets, lack of market information, poor communication infrastructure, and poor transport infrastructure are the barriers to optimising logistics costs.

In terms of logistics, the holding of inventory and transportation are the most important costs for strategic development of enterprises (Cesca, 2006). In 2008, a study was conducted in America to analyse logistics costs. The result show that transportation costs are the most important component at 50%, followed by inventory holding cost at 20%, warehousing being 20%; costs related to customer service/order processing are 7% and administrative costs were 3% of the total cost of logistics (Rushton, 2010).

Transportation costs include the cost of transportation equipment such as equipment depreciation and operating costs such as fuel costs, payroll, toll and insurance (Chao-yang, Hong-rui, & Wei, 2011). Furthermore, rent and maintenance of vehicles , the size and weight of transported goods, travelling distance, number of deliveries, hours of operation (Somuyiwa, 2010), loading capacity, transportation responsibility to the risk of product failure and accidents are drivers of transportation cost (Chao-yang et al., 2011).

Inventory holding costs include the cost of capital, risk, services related to inventory, and variable costs of warehouse space because it depends on the level of inventory (Stock & Lambert, 2001). The most effective factors affecting inventory are purchase method, amount of demand, inventory turnover, changes in inventory levels, and the type of warehouse and the efficiency of data transmission system (Chao-yang et al., 2011).

Nowadays, to provide value advantages in the supply chains companies try to decrease inventory with a higher frequency of replenishment. However, this may lead to an increase in the transportation cost due to the longer travel distances. In addition, inventory holding cost and transportation cost are independent of each other; both function, within the frequency of replenishment, with inverse and direct relationship respectively (see Figure 2.6).

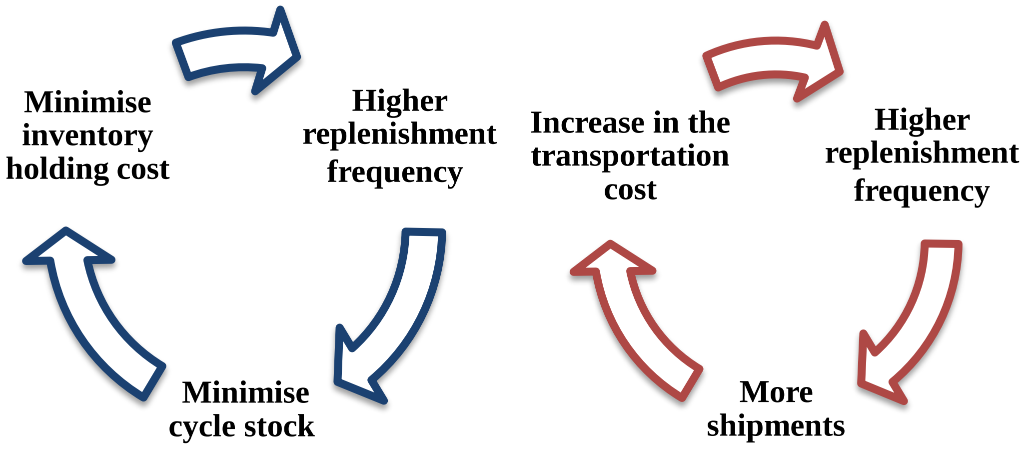


Figure 2. 6: Inventory holding cost and transportation cost relationship

Therefore, the contrast between transportation cost and inventory holding cost has been the focus of planning activities. Viau, Trépanier, & Baptiste (2007) used the Decision Support Systems (DSS) model to integrate inventory control and transportation operation in the spread supply chain by considering delivery frequency and date of delivery to nodes (e.g. Friday and Monday) as variables. Moreover, mathematical models of inventory holding costs and transportation costs are created for the purposes of reducing logistics costs. Qu, Bookbinder, & Iyogun (1999) developed a mathematical model to integrate inventory and transportation policies by considering a central warehouse and several suppliers under stochastic demand during a period time. Hong, Yeo, Kim, Chew, & Lee (2012) presented a model to integrate inventory and transportation for ubiquitous supply chain management and developed a mathematical model in which the demand of products was assumed to be a linear, convex and concave function of price. Chen, Lee, Ip, & Ho (2012) used non-linear programming to minimise both inventory cost and transportation cost. They developed a model with one supplier and several retailers and compared the results with the traditional approach which was based on Economic Order Quantity (EOQ). Kutanoglu & Lohiya (2008) built an inventory model in terms of single-echelon and multi-facility and integrated with both transportation and service responsiveness. They use three alternate modes namely slow, medium and fast in the service parts logistics system. Hong Zhao, Chen, Leung, & Lai (2010) developed an algorithm to solve Markov decision process model which was applied to formulate ordering and delivery problems based on vary transportation modes, costs and inventory issues. Pei, Ye, & Liu (2012) used a bi-level programming method to establish a mathematical model in order to integrate and optimise inventory and transportation cost with probable demand and various products. Swenseth & Godfrey (2002) proposed a method to approximate the actual transportation cost with truckload freight rates incorporated into the inventory replenishment decisions seeking to minimise the total logistics cost. They claimed that the complexity arising from incorporating transportation cost into inventory replenishment policies does not affect the accuracy of decisions. Lee, Chan, Langevin, & Lee (2016) developed an inventory-transportation supply chain model to enhance coordination between single-vendors and multi-buyers. Zhao, Wang, Lai, & Xia (2004) introduced the problem of minimising the production, inventory and transportation costs in a two-echelon system model. They made a trade-off between production, inventory and transportation costs and considered both the fixed cost and the variable cost of the vehicles. Madadi, Kurz, & Ashayeri (2010) addressed a multi-level inventory management decision with transportation cost consideration. They (ibid) developed a decentralised ordering model and centralised ordering model with variable transportation costs in a multi-level environment consisting of one supplier, one warehouse, and multiple retailers. There is some research focused on integration of inventory and transportation in order to minimise logistics costs. However, in terms of fractal supply network, there is very few technical research carried out in this area. The focus of this study in chapter 6, is to optimise logistics cost by investigating the different replenishment frequencies on both transportation and inventory holding through fractal supply network.

2.6. Centralised and decartelised inventory control strategies

Inventory control strategies in supply chain management are classified as either centralised inventory control or decentralised inventory control. Members of supply chains are often separate organisations and independent business enterprises. Despite the benefits of integrated decision making; in practice, they are reluctant to follow the decisions made for all of the members and try to optimise their goals instead of the overall system (Andersson & Marklund, 2000; Jemai & Zied, 2007; Hall & Zhong, 2002). Many researchers consider a supply chain to be a single firm (Axsäter, 1993; Forsberg, 1997; Das & Tyagi, 1997; Seifbarghy & Jokar, 2006) where all policies in the supply chain are defined by single decision maker, who has access to all the necessary information to improve system performance and thus has the power to make decisions. In this case, the members cooperate with each other in accordance with the pre-defined policies. This situation is possible when the whole supply chain is under the control of a centralised decision maker who has a high level of coordination and communication with other members in the supply chain. They investigated centralised models in the two-level supply chains including a central warehouse and multiple retailers with respect to the type of demand distribution function, the type of shortage which were lost-sale or backorder, inventory replenishment policy and stochastic demand. They provided methods to evaluate the total system cost which was consisted of the holding cost at both warehouse and retailers as well as the shortage cost at the retailers.

The principal advantages of using centralised inventory control are to provide better coordination of the inventory replenishments at different levels and different parts of the supply chain and to minimise the total system cost (Ahsan, Arif-Uz-Zaman, & Sultana, 2013; Baboli, Neghab, & Haji, 2008; Marklund, 2002). For larger systems with different organisations, centralised control is often not a viable option due to both technical and managerial problems (Andersson & Marklund, 2000). In chapter 6, this study introduces an inventory control system which is a combination of both centralised and decentralised inventory control strategies thereby leading to an increase in both collaboration and integration throughout the supply network in a fractal environment. Each member of the supply chain has a responsibility to analyse the demand of its downstream customers, determine its safety stock and inventory reorder point and share this with the information centre. This, in turn, must determine the optimum replenishment frequencies for each member to minimise the logistics costs in the supply chain by integrating both inventory holding costs and transportation costs.

2.7. JIT inventory system & Vendor Managed Inventory collaboration

In the recent decades, raw materials and finished goods inventories have become more significant in the supply chains. Traditionally, the necessity of efficient management of inventories, to protect them against theft and possible damage and using a suitable method for inventory turnover, were considered. However, holding inventories can bring enormous costs for the firm that do not create any value added. In response to this problem, the Just-In-Time inventory management system has been the focus for many years (Aghazadeh, 2001; Carnes, Jones, Biggart, & Barker, 2003; Chapman, 1989; Kros, Falasca, & Nadler, 2006; Reid, 1995; Salameh & Ghattas, 2001).

Just-In-Time is a comprehensive control system for production and inventory management. In this system, raw materials will not be bought, and production will not be started if demand is not received. The primary objective of this system is to reduce or eliminate inventory from raw materials to finished goods at all stages of production. Under ideal conditions, a company with Just-In-Time inventories management system only purchase its daily material requirements; there is no work in process at the end of the day and all finished products offered to the customer immediately during the day (Garrison, Noreen, & Brewer, 2003).

Vendor Managed Inventory (VMI) as an innovation system has been conducted in relation to supply chain management in the 1980s. VMI is a mechanism that unifies operational activities in the supply chain in terms of inventory management, transportation planning, pricing policies, etc. In fact, the VMI model is a pull replenishment system which enables the supplier (vendor) to respond quickly to the actual demand. VMI shows the high level of partnership between the vendor and buyer where the vendor is a key decision maker on inventory control. Under this system, the vendor makes a decision about appropriate levels of the buyer inventory for each product (Kumar & Kumar, 2003). Members in the downstream stage (e.g. retailers and distributors) share their demand and selling price information with upstream stage members (e.g. vendor, manufacturer, and supplier) and, in return, the vendor undertakes to control buyer inventory. With this strategy, the buyer will be exempted of all, or part, of its inventory costs and the vendor, by having the customer’s final demand, can improve their production scheduling, transport, and accurate predictions of that demand significantly. It should be noted that the vendor, depending on the structure of the supply chain, can be a manufacturer, a supplier of raw materials, vendor or a major distributor. VMI as a superior approach has been implemented to reduce inventory cost, lead time, the bullwhip effect and improvements in service level in the supply chain in comparison to the traditional approach (Dong & Xu, 2002; Yao, Evers, & Dresner, 2007; Disney & Towill, 2003; Claassen, 2008).

VMI has been widely accepted by many industries. Cooperation between Wal-Mart and Proctor & Gambel (P&G) is a successful example of this approach when, in 1985, timely deliveries of P&G, Wal-Mart's sales and inventory turnover of both sides increased significantly (Haisheng, Amy & Lindu, 2009). In addition to the retail industries, VMI is accepted by large chemical companies in order to increase supply chain efficiency and improve relationships with customers and suppliers (Buzzell &

Ortmeyer, 1995). High-tech industries such as Dell, HP, and SP also used this approach to reduce their inventory levels and costs (Chalener, 2000). In 1988, VMI was accepted by Barilla and its retailer's inventory levels were reduced up to 53% and, in 1990, became the biggest pasta producer in the world (Shah, 2002).

In the traditional supply operation mode, decentralised VMI is the focus (see Figure 2.7). The frequency of the delivery of high-quality components in small shipments and low cost is one of the most important principles of the JIT concept (Banerjee & Kim, 1995; Lee & Ansari, 1985). In this mode, suppliers must produce and keep large batches in the VMI warehouse near to the site of manufacture and deliver components frequently in small batches which cause some problems. Firstly, each supplier has to invest in building warehouses or rent third-party storage facilities to manage or completely outsource to third-party logistics, which incurs high investment costs. Secondly, each of the suppliers has a system for implementing VMI operation. If each supplier provides components at a small scale, maintaining its VMI system requires a high running cost. As a result, the total cost of the VMI systems in the whole supply link is very high. Thirdly, as each supplier runs its own VMI storage independently and dispersedly, there is a lack of information sharing among them. Inevitably, distortion and delay of supply information and demand information occurs, which makes suppliers unable to meet the needs of manufacturers quickly, accurately, and simultaneously. Therefore, as illustrated in Figure 2.8 centralised VMI, as a new collaborative operation mode, has been introduced to resolve the aforementioned problems and facilitate Just In-Time (JIT) production using JIT delivery (Li, Gao, & Ran, 2012).

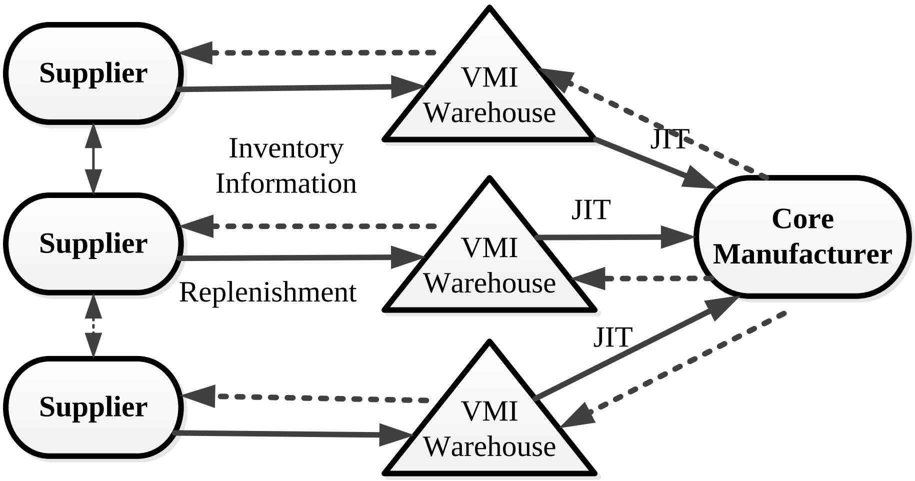


Figure 2. 7: Decentralised VMI operation mode (Li, Gao, & Ran, 2012)

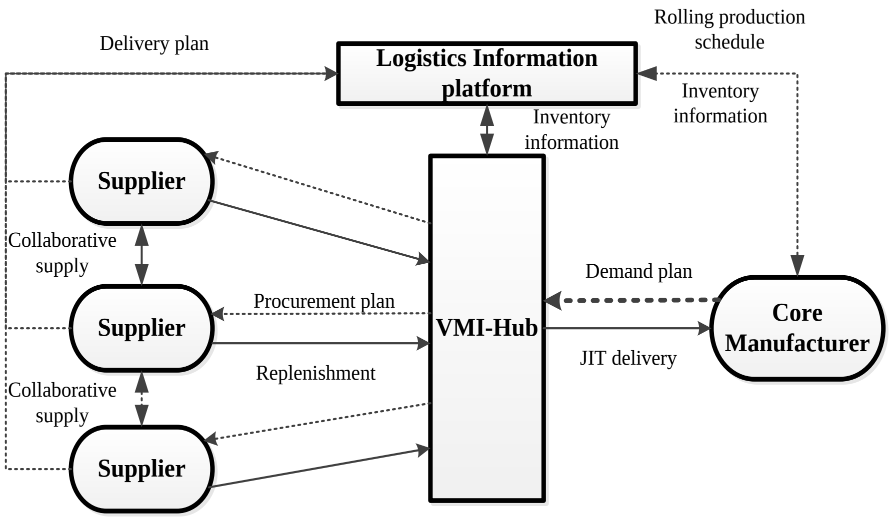


Figure 2. 8: Centralised VMI operation mode (Li, Gao, & Ran, 2012)

2.8. Conclusions

In this chapter, the researcher conducted the literature review which included nine sections.

In section one, a conceptual understanding of fractal supply network and its capabilities were provided and summarised in Tables 2.2 and 2.3, which are considered the basis of this research.

Table 2. 2: Basic Fractal Unit (BFU) functions

Functions	Role
Observers	Monitor, trace and receive data and messages from outer fractals and the environment and transmit composite information to the correspondent functions
Analyser	Use an appropriate method to analyse the current fractal situation based on information provided by the observer and the predefined criteria and transmit the analysis result to the resolver.
Resolver	Includes the decision-making processes based on the information provided by the observer and the results from the analyser.
Organiser	Control and manage the fractal structure to adapt to the continuous change in the environment.
Reporter	Report fractal outputs to outer fractals.

Table 2. 3: Fractal supply network capabilities

Capabilities	Description
Self-similarity	Fractal supply network units are similar to another fractal unit while they can have their own structure
Self-optimisation	Each fractal unit has the ability to improve its performance continuously
Self-organisation	Each fractal unit has the ability to make a decision about its organisation's dimension which is required for a special performance with regards to the environmental parameter and the goals
Goal orientation	Each fractal unit has the ability to generate its goals by coordinating processes between participating fractals and modifying them as needed.
Dynamics	Each fractal unit has the ability to restructure the processes to meet and adapt to the dynamically changing environment

In section two, a comprehensive definition of logistics capability and its classification was conducted and summarised in Table 2.4.

Table 2. 4: Research summary of logistics capabilities

Logistics capability	**Description**	**Elements**
Integration	Integration is a state that exists among internal organizational elements that are necessary to achieve a unity of effort to meet organizational goals.	• Cross-functional unification • Standardization and simplification • Structural adaptation • Compliance • Information system integration
Supply-oriented capability	Focuses on the internal customers' relationship in the supply network with an emphasis on the distribution network to achieve both market value and competitive advantage.	• Selective distribution coverage • Supplier selection, relationship, and involvement • Reverse logistics • Operating across different businesses and different regions
Customer demand-oriented capability	Provides competitive advantage for the firms by stressing product or service differentiation and service enhancement to maximise the external customer satisfaction with unique and value-added activities.	• Customer service focus • Output improvement of products or services • Product or service reconfiguration for the next lifecycle • Use of appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
Information exchange capability	Has a positive relationship with improving firm performance and enables firms to achieve distinct order winner in the marketplace by acquiring, analysing, storing, and distributes information both internally and externally through the supply network	• Information systems development • Development of appropriate information technology • Information sharing • Connectivity
Time management and logistics cost capability	Enables firms to manage both times and cost-effectively to eliminate wasted capital and inventory, minimise logistics cost and increasing responsiveness within a supply network	• Logistics postponement and speculation • Inventory cost • Low total cost distribution • Responsiveness to customer demand fluctuations

In section three above, a conceptual understanding of information sharing was reviewed and the absence of conceptual modelling for information sharing in the supply chain was identified as the gap in this area which needs to be filled from research point of view.

In section four of this chapter, the definition of sustainable supply chain management was provided and sustainability dimensions including environmental, social and economic in supply chain were identified and studied. However, in this study, improvement of the environmental impact through distribution network as one of the major sources of environmental concern within supply chains has received more attention. Thus, later in this section, a comprehensive understanding of the Green Vehicle Routing Problem (GVRP) was presented. GVRP has received the attention by scholars since 2006 and two categories including Green-VRP (G-VRP) and Pollution Routing Problem (PRP) had the most attention in the literature in order to reduce the energy consumption and CO_2 emissions respectively; however, in this research the focuses will be on reducing the CO_2 emission.

In section five, the logistics cost concept and its constituent elements were discussed and logistics cost reduction through the integration of both inventory holding cost and transportation cost was reviewed.

In section six, two types of inventory control strategies in supply chain management are introduced; centralised inventory control and decentralised inventory.

In section seven, the collaboration between JIT inventory system and Vendor Managed Inventory (VMI) is discussed.

In section eight, the conclusion and research focus of this study are presented. In the next chapter, the proposed methodologies to be used in this research will be discussed and the framework for configuring/reconfiguring fractal supply network and logistics capabilities will be proposed.

Chapter Three - Research Methodology

This chapter describes the methodologies employed to answer the research questions and the framework developed for configuring the fractal supply network and logistics capabilities. First, a brief introduction is presented, next, the major methodologies including conceptual modelling, decision-making and modelling and analysing are summarised. Later in the chapter, the framework of configuring fractal supply network and logistics capabilities is proposed.

3.1. Introduction

The fractal supply network and logistics capabilities problems will be solved based on fractal supply network capabilities. A full understanding of the fractal concept is a key to capturing and managing its inherent complexities. In previous chapter, the fractal supply network capabilities and fractal functions are defined to enhance the practitioners understanding of this type of relationship. Conceptual understanding of logistics capabilities and its classification and some selected concepts also are presented.

In the following sections the methodologies employed in this study are outlined.

3.2. Conceptual modelling

Conceptual modelling is the first stage towards formal modelling and analysis and decision-making of the identified problems in the fractal supply network configuration. It provides a comprehensive descriptive representation of the problems. In this study, the conceptual modelling for measuring and optimising logistics capabilities in the fractal supply network is provided as the main task of this methodology.

3.3. Decision Making

In order to measure logistics capability within fractal supply network, a Multiple Criteria Decision Making (MCDM) model is used in which practitioners should be able to decide upon the different logistics capability factors, sub-factors and key elements to test and assess and improve an enterprise's logistics capability. MCDM refers to a decision-making process with different and sometimes contradictory multiple criteria (Cho, 2003) which helps the decision maker in the identification, description, evaluation, ranking, grouping and selection of the alternatives (De Montis, De Toro, Droste-Franke, Omann, & Stagl, 2000). MCDM consists of two main sub-groups; Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making

(MODM). With regard to the matter investigated, decision-making problems in this research that were intended were known as MADM.

MADM was first introduced by Churchman, Ackoff & Arnoff in 1957 (De Montis et al., 2000). Tecle (1988) identified more than seventy multi-criteria techniques though, undoubtedly, this number is much higher today. While, generally, they provide three types of the solution including choosing the alternative that presents the greatest amount of satisfaction for the decision maker from among the sets of alternatives, insert all the alternatives in restricted groups and ranking and prioritising all of the alternatives.

The relative importance of the measurement criteria is assessed using the analytical hierarchy process (AHP) and the fuzzy-AHP which are described in detail in the following sections.

3.3.1. Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) is one of the most widely-used methods in the Multiple Attribute Decision-Making (MADM) problem which was proposed in 1980 by Thomas L. Saaty. Scope and a variety of used AHP in different areas such as evaluation, cost-benefit analysis and allocation, planning and development, priority and ranking, decision making, forecasting and strategic planning, which have been very extensive (Vaidya & Kumar, 2006). This technique formulated the problem in a hierarchical format, combining both quantitative and qualitative criteria at the same time, involving different alternatives in decision-making, and providing a sensitivity analysis on criteria and sub-criteria. In addition, AHP is built based on a pairwise comparison which facilitates both the judgments and calculations. Moreover, the technique presents the consistency and inconsistency of the decision which are the distinctive advantages of this technique (Saaty & Sodenkamp, 2008).

Saaty (1990) expressed AHP properties as follows:

- Unity: AHP is a unique model; simple and flexible for solving a wide range of problems that are without structure which is easily understandable to anyone.
- Complexity: To solve the complex problems, AHP uses both systematic approach and partial analysis simultaneously.
- Inter-dependence: AHP considers the dependence linearly while solving problems that are related to the non-linear elements, also AHP is used.
- Hierarchy structuring: This process organises elements of a system hierarchically with this type of organisation matching human thinking and elements are classified at different levels.
- Measurement: AHP provides a scale for measuring the qualitative criteria and a method to estimate the priorities.
- Consistency: AHP calculates and presents the logical consistency of judgments which are used for determining the priorities.
- Synthesis: This process estimates the final ranking of the alternatives.
- Trade-offs: AHP considers the priorities which are related to the elements in a system and makes a balance between them to enable decision makers to choose the best alternative based on their goals.
- Judgment and Consensus: This process places no insistence on consensus but can offer a combination of different judgments.
- Process Repetition: This process enables the decision makers to correct their definition of a problem and improve the judgment and decision.

Analytical Hierarchy Process steps can be explained as follows briefly:

- Step 1: Constructing the hierarchical model. AHP is a graphical representation of a real, complex problem where the overall goal is the top of the hierarchical model, followed by main-criteria and sub-criteria in the subsequent levels and, finally, at the lowest level possible, alternatives are placed. This situation provides a general and standardised framework that, for all problems regardless of their type, will be identical (see Figure 3.1). The criteria for the performance evaluation of each dimension should be mutually independent (Saaty, 1988).

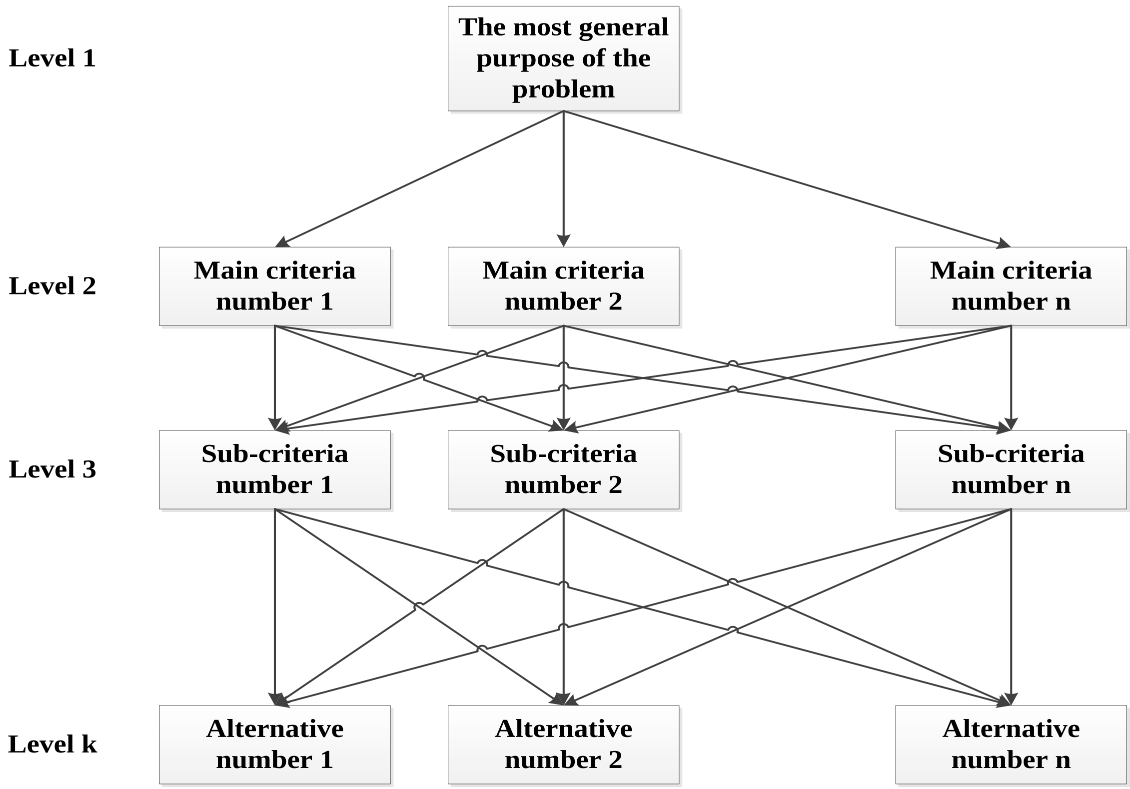


Figure 3. 1: Analytical Hierarchy Process Framework

- Step 2: A pairwise comparison of criteria and alternatives for development of judgment matrices. This step includes the pair-wise comparison of elements which are inserted in each level of the hierarchical model with respect to the main goal or elements in the higher level performed by decision makers to find the comparative weights among the attributes of the decided element and are inserted in the matrix, namely the "pair-wise comparison matrix". The scale for these pair-wise comparisons are introduced based on a standard evaluation scheme as shown in table 1, which enables the decision-makers to express preference or importance between each pair of elements with respect to the main goal or higher criterion by incorporating their experience and knowledge (Saaty, 1988; Saaty & Vargas, 1994).

Table 3. 1: Scale of Relative Importance

Intensity of importance	Definition	Explanation
1	Equally important	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favour one activity over another
5	Strong Importance	Experience and judgment strongly favour one activity over another
7	Very strong Importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

- Step 3: Derivation of priorities: After a pair-wise comparison is completed, the next step is to calculate the local priorities from the judgment matrices. The Eigen value Method (EVM), the Logarithmic Least Squares Method (LLSM), the Weighted Least Squares Method (WLSM), the Goal Programming Method (GPM) and the Fuzzy Programming Method (FPM) are the main calculation methods summarised by (Mikhailov, 2000). In this study, Normalised Geometric Mean (NGM) and EVM are considered.
- Step 4: Synthesizing the results: After obtaining the local priorities for the criteria, sub-criteria and the possible alternatives through pairwise comparisons, the final priorities of the elements are located in the k^{th} level of the hierarchical model, with respect to the main goal, will be calculated.

3.3.2. Data collection and analysis tool

During this work, information is collected through three steps separately: In the first step, the logistics capabilities criteria and their elements are extracted and the conceptual model of logistics capabilities in fractal supply network is developed using the relevant literature, and conducting interviews with managers and experts. Then, a questionnaire to carry out a pairwise comparison between the criteria and sub-criteria within the proposed model based on fractal supply network is designed to gather the opinion of the practitioners, researchers and industrialists. The questionnaire is one of the most common methods for collecting data in such type of research. As one of the general characteristics of the questionnaire, the ease of collecting a lot of processed data can be noted (Dornyei & Taguchi, 2010). The questionnaire, a written tool, consists of a series of questions related to the fact that respondents respond to it or among the available answers to choose the correct one (Brown, 2001).

In the following, ‘Expert Choice’ software is used to determine the relative weight of functional measures. ‘Expert Choice’ is professional software available commercially and designed for implementing AHP. The Expert Choice is used to structure the decision into criteria and alternatives, their pairwise comparisons, synthesize criteria and subjective inputs to arrive at a prioritised list of alternatives, and report on the sensitivity analysis. Moreover, ‘Excel’ software is also used to perform various operations to prepare the data, such as geometric mean calculations.

3.3.3. Validation of the model contents

Criteria and sub-criteria proposed in the model were extracted from thematic literature and also from previous experience. The designed questionnaire was piloted within our research team to be tested before the publicity stage, then after receiving the research team's comments; the questionnaire was finally designed and broadcasted to collect the data. All the responders agreed about the final proposed model and showed positive responses towards logistics capability in the fractal supply network and its necessity.

3.3.4. Reliability

Since the questionnaire of the present study is in the form of pairwise matrices, its reliability is measured using a consistency ratio. This mechanism shows the extent to which the judgements and priorities can be trusted. In general, a consistency ratio with equal or less than ten percent can be taken as sufficiently consistent.

(Satty, 1980) suggested using the consistency index to measure the degree of consistency using the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.1}$$

Where:

CI= Consistency index

λmax= Maximal eigenvalue

n= Dimension of the square matrix

Then, the consistency ratio is generated by the comparison of the value of consistency index and the random indices:

$$CR = \frac{CI}{RI} \tag{3.2}$$

Where:

CR= Consistency Ratio

RI= Random Consistency Index

Where the Random Consistency Index (RI) can be derived based on the dimension of the square matrix (n) (see Table 3.2).

Table 3. 2: Random Indices (Ishizaka & Labib, 2009)

n	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Since the research consistency ratio is less than 0.1, As a result, the research questionnaire is confirmed.

3.3.5. FUZZY-AHP

The AHP method bears comparison to human thinking. AHP breaks down a complex decision-making process into simple comparisons. However, it does not consider cognitive factors of human judgement (Sarfaraz, Mukerjee, & Jenab, 2012). Uncertainty in the preference judgements increases the uncertainty in the prioritisation of alternatives and, to the same ratio; it makes it difficult to determine the logical consistency of the priorities (Leung & Cao, 2000). Therefore, to overcome these problems Fuzzy-AHP is provided. There are several methods proposed in the literature for using Fuzzy-AHP (Buckley, 1985; Chang, 1996; Van Laarhoven & Pedrycz, 1983). In this research, the extent analysis method (Chang, 1996), due to its popularity, has been used based on triangular fuzzy numbers (TFNs) to measure logistics capabilities in the fractal supply network.

In summary, the purpose of Fuzzy-AHP is to deal with a complex decision-making problem by decomposition of these problems into a hierarchy with the main goal (criterion) at the top, and, then, the criteria and sub-criteria and possible alternatives at the bottom level. All the elements are compared, in pairs, to assess its relative importance in the level as well as the level above; the method computes eigenvectors until the composite final vector is obtained. The final vector of weights (global weight) shows the relative importance of each alternative towards the main goal (Sharma & Yu, 2014).

Fuzzy AHP is a range of values used to deal with uncertainties for decision makers (see Table 3.3).

Table 3. 3: Triangular Fuzzy Conversion Scale (Prakash, 2003)

Importance Intensity	Triangular Fuzzy scale	Importance Intensity	Triangular Fuzzy Scale
1	(1,1,1)	1/1	(1/1, 1/1, 1/1)
2	(1,2,4)	1/2	(1/4, 1/2, 1/1)
3	(1,3,5)	1/3	(1/5, 1/3, 1/1)
5	(3,5,7)	1/5	(1/7, 1/5, 1/3)
7	(5,7,9)	1/7	(1/9, 1/7, 1/5)
9	(7,9,11)	1/9	(1/11, 1/9, 1/7)

Consider a triangular fuzzy comparison matrix expressed by:

$$\tilde{A} = (\tilde{a}ij)_{n\times n} \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{21}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1) \end{bmatrix}$$

Where

$$\tilde{a}_{ij} = \begin{cases} 1 & i = j \\ (l_{ij}, m_{ij}, u_{ij}) \ or \ (\frac{1}{u_{ij}}, \frac{1}{m_i}, \frac{1}{l_{ij}}) & i \neq j \end{cases}$$

Where:

l= The lower bound of the triangular fuzzy set

m= The mean bound of the triangular fuzzy set

u= The upper bound of the triangular fuzzy set

i= The row number

j= The column number

In this study, a priority vector is determined by the aforementioned triangular fuzzy comparison matrix, the extent analysis method is used, and its steps are described briefly as follows:

Firstly, determine the synthetic extent value, which is a triangular fuzzy number, for each row of fuzzy pairwise comparison matrix:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{3.3}$$

Where:

S_i= The synthetic extent value

M_{gi}^{j}= The triangular fuzzy numbers of pair wise comparison matrix

Where

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \tag{3.4}$$

And

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right) \tag{3.5}$$

And

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \tag{3.6}$$

Secondly, determine the degree of possibility of triangular fuzzy numbers (S_i). In general, if M_1= (l_1, m_1, u_1) and M_2= (l_2, m_2, u_2) be the two triangular fuzzy numbers, in accordance with figure 3.2, the degree of possibility of M_1 toward the M_2 can be defined as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = u_{M_2}(d)$$

$$= \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{3.7}$$

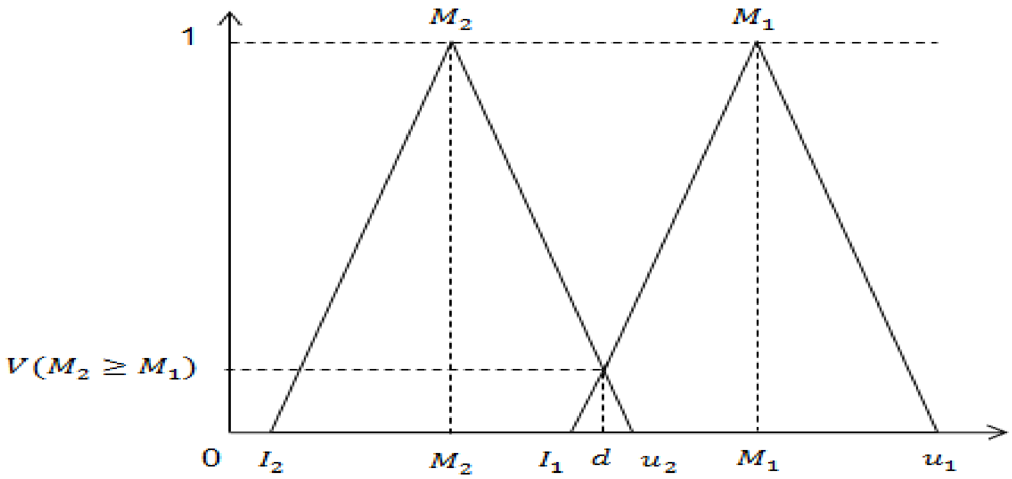


Figure 3. 2: The Intersection between TFNs (Chang, 1996)

Moreover, the degree of possibility of a convex fuzzy number to be greater than *k* convex fuzzy numbers can be defined as follows:

$$V(M \geq M_1, M_2, \ldots, M_K) = V[(M \geq M_1)\ and (M \geq M_1)\ and \ldots and\ (M \geq M_k)]$$

$$= Min\ V\ (M \geq M_i), = 1, 2, 3, \ldots, k. \tag{3.8}$$

Thirdly, determine the weights of criteria, sub-criteria and possible alternatives:

$$d'(A_i) = Min\ V\ (S_i \geq S_k) \quad k = 1, 2, \ldots, n\ ,\ \ k \neq i \tag{3.9}$$

Fourthly, determine the weight vector:

$$W' = \left(d'(A_1), d'(A_2), \dots, d'(A_n)\right)^T \tag{3.10}$$

Finally, via normalization, the normalised weight vectors:

$$W = \left(d'(A_1), d'(A_2), \dots, d'(A_n)\right)^T, W \neq \ fuzzy\ number \tag{3.11}$$

3.4. Modelling and Analysis

Fractal supply network configuration and logistics capabilities modelling are performed using quantitative models and simulation. The purpose of this stage is to achieve a number of good solutions for the final implementation. During this stage, in accordance with understanding the mathematical equations governing the problem, the mathematical models are developed. The proposed mathematical models are tested through the hypothetical supply network and validated using simulation software. Finally, experimental design is used to generate and analyse the results. The purpose of the implementation of the experimental design is to obtain the maximum possible information with a minimum number of experiments. An experiment is the set of planned trials in which factors (independent variables) that are believed to have an effect on the objectives, are just systematically changed and the output (objectives value/dependent variables) are measured and recorded. In general, there are two types used for designing an experiment; full factorial design and fractional factorial design (Montgomery, 2008; Hachicha, Ammeri, Masmoudi, & Chabchoub, 2010). In this research, factorial design and statistical technique (MANOVA) is used to obtain information in relation to all decision variables and relationships between them.

3.4.1. Simulated annealing

Simulated annealing algorithm is an effective meta-heuristic optimisation algorithm for solving optimisation problems presented by Kirkpatrick, Gelatt & Vecchi, (1983) and adapted from the Metropolis-Hastings algorithm (Metropolis, Rosenbluth, Rosenbluth, Teller, & Teller, 1953). They proposed a gradual freezing technique to solve the hard optimisation problems. The main advantage of the simulated annealing algorithm is its ability to not remain at the optimal local point and move to the global optimum point.

In generic term, the algorithm consists of two loops: one loop reduces the temperature from the initial temperature to the final temperature and the second loop identifies the number of repetitions at each temperature. The factors affecting the timing of temperature reduction include the initial temperature, the final temperature, how to reduce the temperature and the number of repetitions in each temperature.

Simulated annealing algorithm starts from an initial answer and then, in a repeated loop, it moves to neighbouring answers. If the neighbour's answer is better than the current one, the algorithm puts it as the current answer. Otherwise, the algorithm accepts that answer with the probability of $exp\ (-\Delta E\ /\ T)$ as the current answer. In this regard, ΔE is the difference between the objective function of the current answer and the neighbour's answer and T is a parameter called temperature. At each temperature, several repetitions are performed, and then the temperature is slowly reduced. In the initial steps, the temperature is set very high, so it is more likely to accept worse answers. With the gradual decrease of temperature, in the final steps, there will be fewer probabilities for accepting worse answers, and so the algorithm converges to a good answer. Figure 3.3 illustrates the general structure of the simulated annealing algorithm.

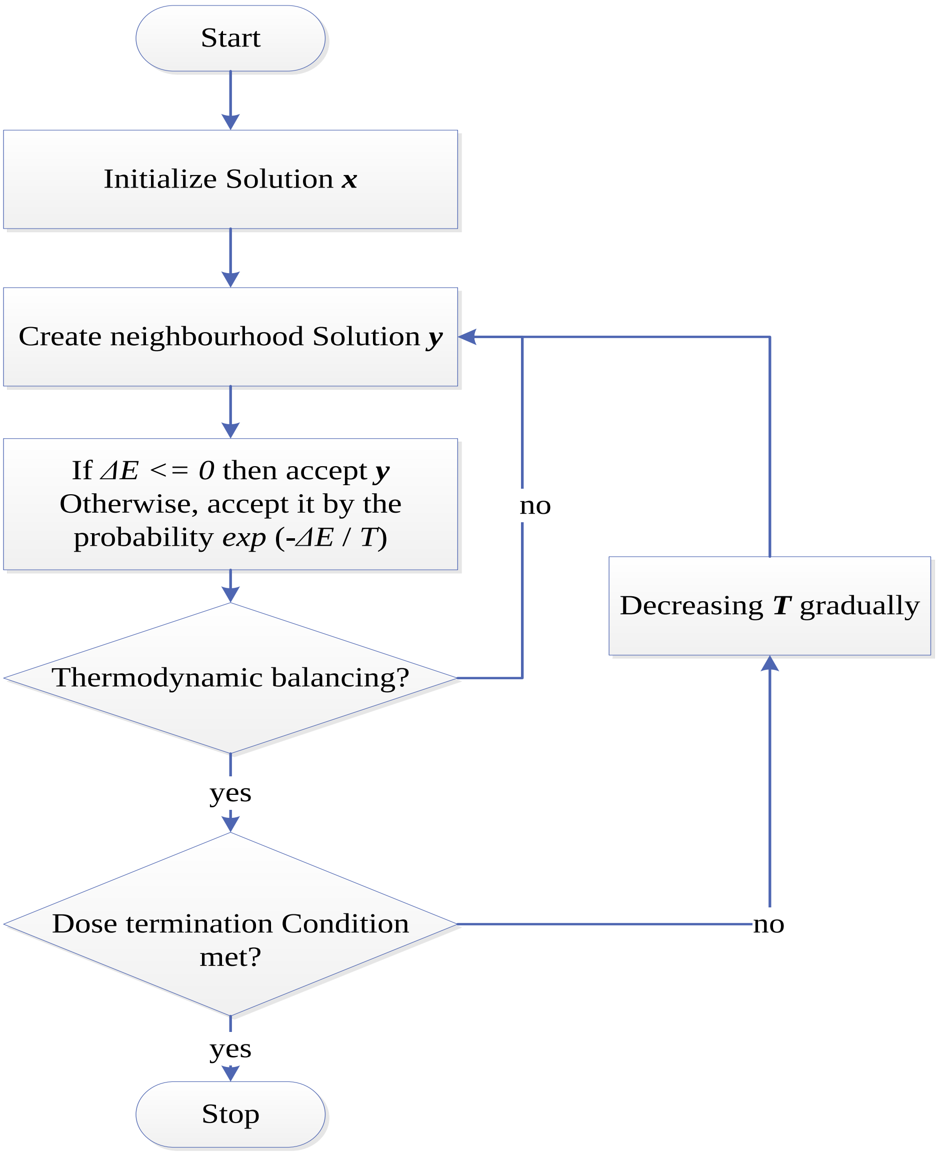


Figure 3. 3. Simulated annealing algorithm flow chart

3.5. Proposed Framework

Figure 3.4 displays the framework for fractal supply network configuration/reconfiguration and logistics capabilities and where it is covered in the thesis.

Configuration/reconfiguration is started with developing conceptual models based on the changes in the environments with respect to fractal supply network capabilities (e.g. Self-similarity, Self-organisation, Self-optimisation, Goal-orientation and Dynamics).

The scope of configuration/reconfiguration covers both optimisation and measurement. As part of the measurement, in terms of logistics capabilities prioritisation, Multi-Criteria Decision-Making (MCDM) method is used to specify high-priority logistics capabilities for further investment planning. The relative importance of the measurement criteria is assessed using analytical hierarchy process (AHP) and Fuzzy-AHP.

In terms of optimisation, mathematical and simulation models regarding the problems with respect to conceptual models are developed and tested hypothetically and verified and validated using simulation tools. Experimental factorial design and statistical techniques are used to generate and analyse the results.

By accepting the results in the previous step, implementation of the developed models in the real area of problems will be considered which deal with both logical and physical aspects of implementation.

The performance of the established configuration/reconfiguration needs to be monitored and evaluated in accordance with decision-making criteria which are used during the decision making, and key performance indicators which are used during the modelling and analysis step.

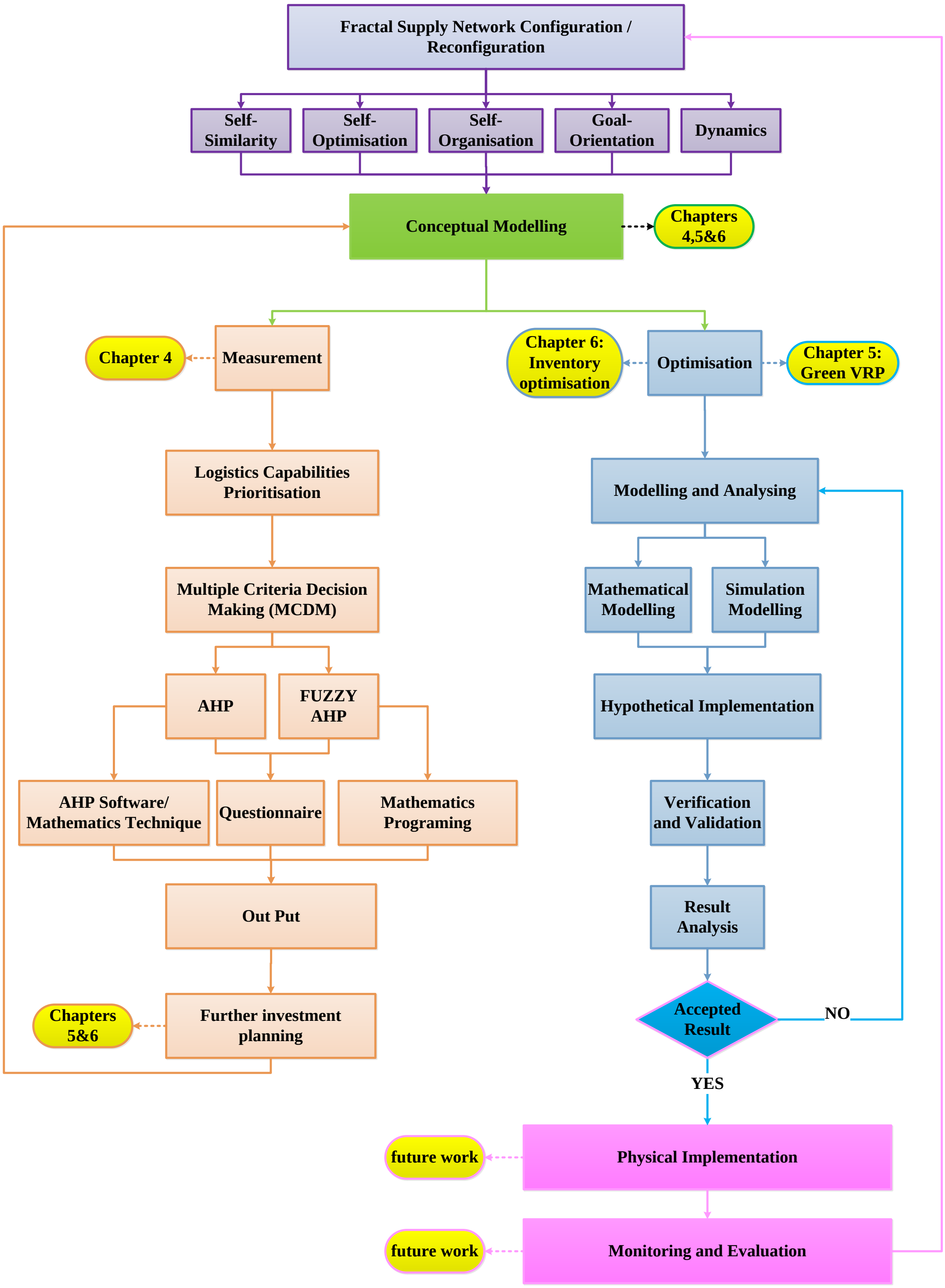


Figure 3. 4: Fractal supply network configuration with focus on its logistics capability

Chapter Four - Measurement of logistics capability in the fractal supply network

The purpose of this chapter is to develop a Fuzzy-AHP multi-criteria decision-making model to measure logistics capability in the fractal supply network. At the beginning of this chapter, a conceptual model of logistics capabilities in fractal supply network is developed. Next, two methodologies are used for pairwise comparison and prioritisation of criteria; classical AHP and Fuzzy AHP. Later in the chapter, results comparison between the classical AHP and Fuzzy-AHP is provided. In addition, the dynamic sensitivity of Expert Choice was applied to dynamically change the priorities of the main criteria to determine how these changes affect the priorities of the lower sub criteria. Finally, the overall conclusion is given as the last part of this chapter.

4.1. A conceptual model of logistics capabilities in the fractal supply network

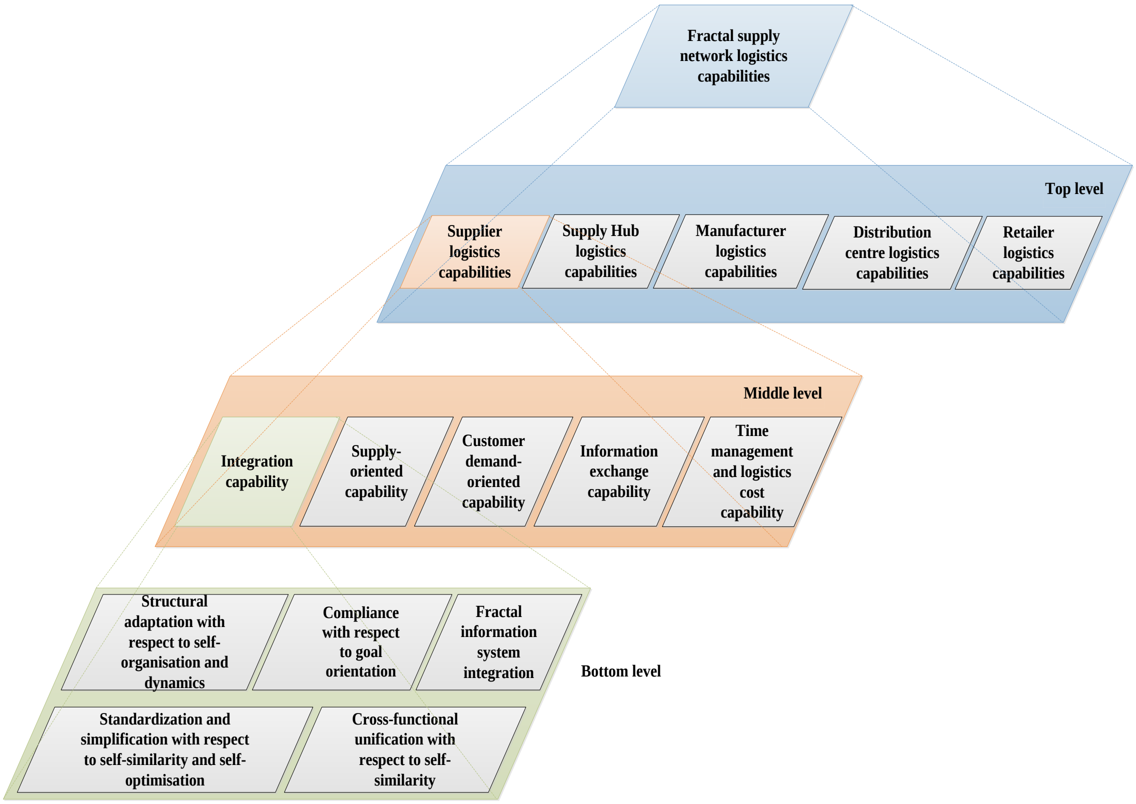


Figure 4. 1: Conceptual model of logistics capabilities in the fractal supply network

4.2. Application of the AHP

It is clear that from figure 4.1 that the AHP is the most appropriate method to represent the hierarchical structure of the logistics capabilities in the fractal supply network. Therefore, in this section, the usage of AHP method for evaluating importance priority of main criteria, sub-criteria and lower sub criteria in fractal supply network is explained.

4.2.1. Structuring the hierarchy

The first step of using AHP to model a decision problem is to structure the hierarchy.

With respect to the proposed conceptual structure, which is presented in the previous section, the hierarchical model is developed as shown in figure 4.2.

The main goal of this research is to measure logistics capabilities in the fractal supply network and is placed at the top of the hierarchical model. From which, five criteria are descended in the second level (e.g. Supplier, supply hub, manufacture, distribution centre and retailer). This is followed by five major logistics capabilities factors (e.g. Integration, supply-oriented, customer demand-oriented, information exchange, and time management and logistics cost) located in the third level as sub-criteria under each criterion and logistics capabilities elements (e.g. Cross-functional unification with respect to self-similarity, etc.) as lower sub-criteria located under the relevant logistics capabilities factor in the fourth level.

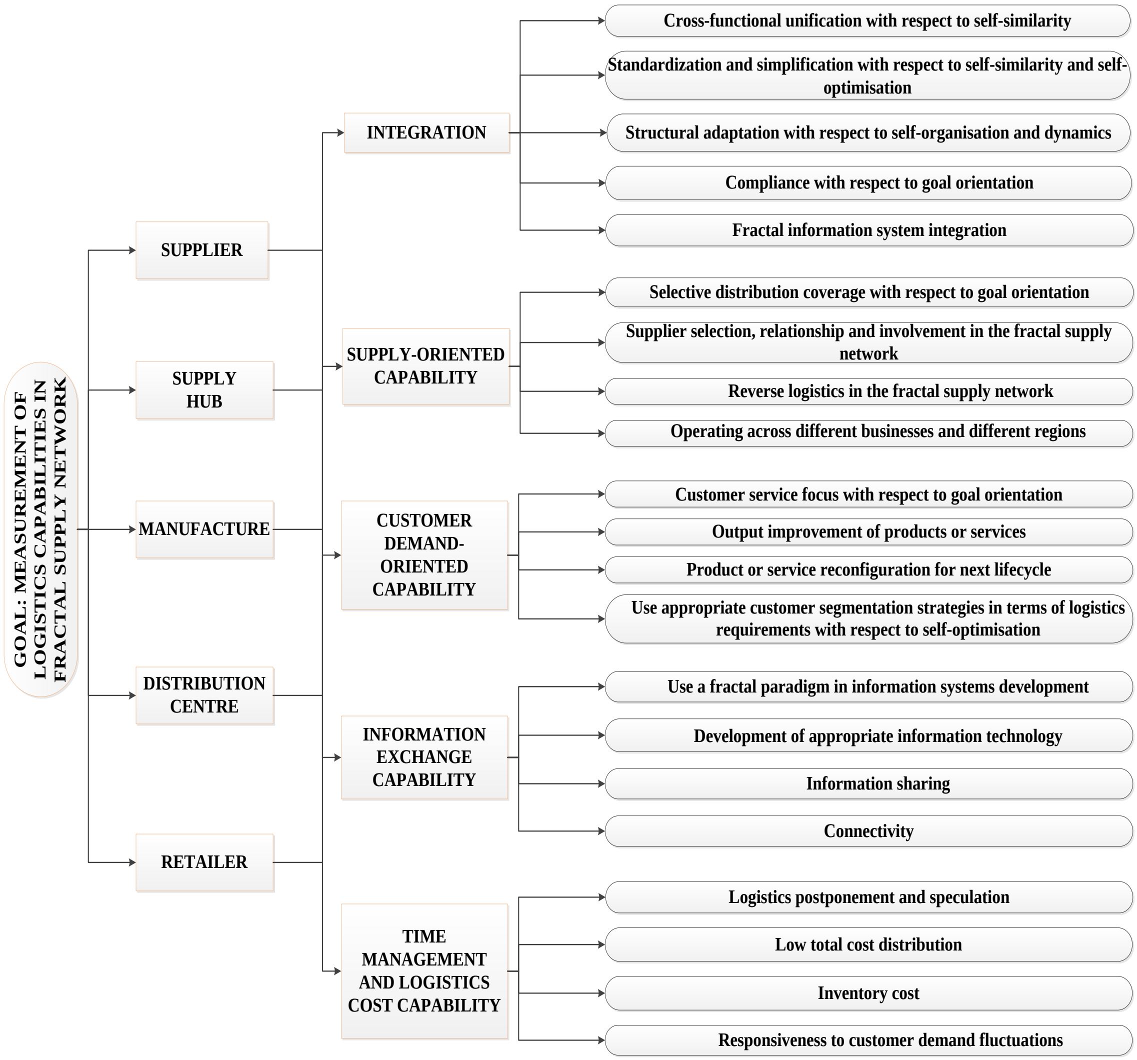


Figure 4. 2: The proposed multi-criteria decision-making model

4.2.2. Performing pairwise comparisons

Pairwise comparisons were performed systematically to include all the combinations of main criteria, sub-criteria and lower sub criteria relationships. For that, a questionnaire was designed for data collection purposes from academics and industrialists who were recognised and selected carefully by research team as professional experts in this particular research area. The questionnaire was developed based on the criteria and levels in the AHP model. Experts who have been asked to make pair-wise comparisons between the two factors/criterion at a time, decide which factor is more important and then specify the degree of importance on a scale between one (equal importance) and nine (absolutely more important) of the most important factor/criteria. In total, 50 people responded to the questionnaire survey and, of them, 18 were academics and 32 were industrialists. All the responders agreed about the proposed model and showed positive responses towards logistics capability in the fractal supply network and its necessity.

The data collected from the questionnaire survey has been converted into a geometric mean to measure the pair wise comparison of each criterion. Among the responses from the feedback, all the participants agreed with the model. As different participants each have different opinions about each criterion, a geometrical mean method is used to convert the different judgements into one figure for each criterion and sub-criteria.

The following formula is used to calculate the geometric mean.

$$\text{Geometric mean} = [(x_1)(x_2)(x_3) \dots (x_n)]^{1/n} \qquad (4.1)$$

Where

x= Individual weight of each judgment

n = Sample size (number of judgment)

4.2.2.1. Main criteria pairwise comparisons

Table 4.1 shows the comparison matrix of the main criteria '*Supplier*, *Supply Hub*, *Manufacturer*, *Distribution centre* and *Retailer*' with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".

Table 4. 1: Comparison matrix of main criteria with respect to the main goal "A Fractal supply network logistics capability measurement"

	Supplier	**Supply hub**	**Manufacturer**	**Distribution centre**	**Retailer**
Supplier	1	3	1	2	3
Supply hub	1/3	1	1/3	2	1
Manufacturer	1	3	1	3	3
Distribution centre	1/2	1/2	1/3	1	2
Retailer	1/3	1	1/3	1/2	1

4.2.2.2. Sub-criteria pairwise comparisons

Figures displayed in Tables 4.2-4.6 are calculated from the questionnaires and demonstrate the comparison matrices of the sub-criteria '*Integration*, *Supply-oriented capability*, *Customer demand-oriented capability*, *Information exchange capability* and *Time management and logistics cost capability*' with respect to the main criteria "Supplier, Supply hub, Manufacturer, Distribution centre and Retailer" respectively.

Table 4. 2: Comparison matrix of sub-criteria with respect to the "Supplier"

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	1	3	3	2	2
Supply-oriented capability	1/3	1	1/2	1	2
Customer demand-oriented capability	1/3	2	1	2	2
Information exchange capability	1/2	1	1/2	1	2
Time management and logistics cost capability	1/2	1/2	1/2	1/2	1

Table 4. 3: Comparison matrix of sub-criteria with respect to the "Supply hub"

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	1	1/3	3	3	3
Supply-oriented capability	3	1	3	5	3
Customer demand-oriented capability	1/3	1/3	1	5	1
Information exchange capability	1/3	1/5	1/5	1	1/3
Time management and logistics cost capability	1/3	1/3	1	3	1

Table 4. 4: Comparison matrix of sub-criteria with respect to the "Manufacturer"

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	1	3	1/3	1	1/3
Supply-oriented capability	1/3	1	1/3	1/5	1/5
Customer demand-oriented capability	3	3	1	1	1/5
Information exchange capability	1	5	1	1	1/5
Time management and logistics cost capability	3	5	5	5	1

Table 4. 5: Comparison matrix of sub-criteria with respect to the "Distribution Centre"

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	1	1/3	1/3	1/3	1/3
Supply-oriented capability	3	1	1	1/3	1/5
Customer demand-oriented capability	3	1	1	1/5	1/3
Information exchange capability	3	3	5	1	1
Time management and logistics cost capability	3	5	3	1	1

Table 4. 6: Comparison matrix of sub-criteria with respect to the "Retailer"

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	1	1/3	1/3	3	3
Supply-oriented capability	3	1	1/2	5	3
Customer demand-oriented capability	3	2	1	3	5
Information exchange capability	1/3	1/5	1/3	1	1/3
Time management and logistics cost capability	1/3	1/3	1/5	3	1

4.2.2.3. Lower sub criteria pairwise comparisons

Tables 4.7-4.11 present the comparison matrices of the lower sub-criteria (e.g. cross-functional unification) with respect to the relevant sub-criteria (e.g. Integration).

Table 4. 7: Comparison matrix of lower sub-criteria with respect to the "Integration"

	Cross-functional unification with respect to self-similarity	**Standardization and simplification with respect to self-similarity and self-organisation**	**Structural adaptation with respect to self-organisation and dynamics**	**Compliance with respect to goal orientation**	**Fractal information system integration**
Cross-functional unification with respect to self-similarity	1	1/3	1	2	1/2
Standardization and simplification with respect to self-similarity and self-organisation	3	1	1	2	1/2
Structural adaptation with respect to self-organisation and dynamics	1	1	1	1/2	1/3
Compliance with respect to goal orientation	1/2	1/2	2	1	1/3
Fractal information system integration	2	2	3	3	1

Table 4. 8: Comparison matrix of lower sub-criteria with respect to the "Supply-oriented capability"

	Selective distribution coverage with respect to goal orientation	**Supplier selection, relationship and involvement in the fractal supply network**	**Reverse logistics in the fractal supply network**	**Operating across different businesses and different regions**
Selective distribution coverage with respect to goal orientation	1	1/3	3	3
Supplier selection, relationship and involvement in the fractal supply network	3	1	3	3
Reverse logistics in the fractal supply network	1/3	1/3	1	1
Operating across different businesses and different regions	1/3	1/3	1	1

Table 4. 9: Comparison matrix of lower sub-criteria with respect to the "Customer demand-oriented capability"

	Customer service focus with respect to goal orientation	**Output improvement of products or services**	**Product or service reconfigura tion for next lifecycle**	**Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation**
Customer service focus with respect to goal orientation	1	3	3	3
Output improvement of products or services	1/3	1	2	1
Product or service reconfiguration for next life cycle	1/3	1/2	1	1/2
Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation	1/3	1	2	1

Table 4. 10: Comparison matrix of lower sub-criteria with respect to the "Information exchange capability"

	Use a fractal paradigm in information systems development	**Development of appropriate information technology**	**Information sharing**	**Connectivity**
Use a fractal paradigm in information systems development	1	2	2	1
Development of appropriate information technology	1/2	1	1	1
Information sharing	1/2	1	1	1
Connectivity	1	1	1	1

Table 4. 11: Comparison matrix of lower sub-criteria with respect to the "Time management and logistics cost capability"

	Logistics postponement and speculation	**Inventory cost**	**Low total cost distribution**	**Responsiveness to customer demand fluctuations**
Logistics postponement and speculation	1	1	3	1
Inventory cost	1	1	3	1/3
Low total cost distribution	1/3	1/3	1	1/3
Responsiveness to customer demand fluctuations	1	3	3	1

4.2.3. Derivation of priorities (AHP)

In this study, Normalised Geometric Mean (NGM) and Eigen Value Method (EVM) are adapted to drive the local priorities of the criteria, sub-criteria and lower sub criteria.

4.2.3.1. Application of Normalised Geometric Mean (NGM)

In this method, the geometric mean of the elements of each matrix's row is calculated (see equation 4.2) and divided by the column sum of row geometric means to derive the priorities within the comparison matrices (see Tables 4.12-4.22).

$$GM_R = \sqrt[n]{x_1, x_2, x_3, x_n} \qquad (4.2)$$

Where:

GM_R= Geometric mean of each matrix's row

In terms of main criteria, as shown in Table 4.12, *Manufacturer* was the most important criterion (manufacturer = 0.338) followed by *Supplier* (0.312), *Supply hub* (0.130), *Distribution Centr*e (0.122) and *Retailer* with the least ranking (0.098) with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".

Table 4. 12: Normalized geometric mean of the main criteria with respect to the main goal "A Fractal supply network logistics capability measurement"

Main criteria	Geometric mean	Normalized values
Supplier	$\sqrt[5]{1\times3\times1\times2\times3}=1.78$	0.312
Supply hub	$\sqrt[5]{0.33\times1\times0.33\times2\times1}=0.74$	0.130
Manufacturer	$\sqrt[5]{1\times3\times1\times3\times3}=1.93$	0.338
Distribution Centre	$\sqrt[5]{0.5\times05\times0.33\times1\times2}=0.70$	0.122
Retailer	$\sqrt[5]{0.33\times1\times0.33\times0.5\times1}=0.56$	0.098
Total	5.72	1.000

In accordance with the sub-criteria, *Integration* was the most important sub-criteria (0.371) with respect to "Supplier". However, with respect to "Supply hub, Manufacturer, Distribution Centre and Retailer" *Supply-oriented capability* (0.427), *Time management and logistics cost capability* (0.500), both *Information exchange capability* and *Time management and logistics cost capability* (0.348) and *Customer demand-oriented capability* (0.392) were the most important sub-criteria respectively (see Tables 4.13-4.17).

Table 4. 13: Normalized geometric mean of the sub-criteria with respect to 'Supplier'

Sub-criteria	Geometric mean	Normalized values
Integration	$\sqrt[5]{1\times3\times3\times2\times2}=2.05$	0.371
Supply-oriented capability	$\sqrt[5]{0.33\times1\times0.5\times1\times2}=0.80$	0.146
Customer demand-oriented capability	$\sqrt[5]{0.33\times2\times1\times2\times2}=1.22$	0.221
Information exchange capability	$\sqrt[5]{0.5\times1\times0.5\times1\times2}=0.87$	0.158
Time management and logistics cost capability	$\sqrt[5]{0.5\times0.5\times0.5\times0.5\times1}=0.57$	0.104
Total	5.51	1.000

Table 4. 14: Normalized geometric mean of the sub-criteria with respect to 'Supply hub'

Sub-criteria	Geometric mean	Normalized values
Integration	$\sqrt[5]{1\times0.33\times3\times3\times3}=1.55$	0.248
Supply-oriented capability	$\sqrt[5]{3\times1\times3\times5\times3}=2.67$	0.427
Customer demand-oriented capability	$\sqrt[5]{0.33\times0.33\times1\times5\times1}=0.89$	0.142
Information exchange capability	$\sqrt[5]{0.33\times0.2\times0.2\times1\times0.33}=0.34$	0.054
Time management and logistics cost capability	$\sqrt[5]{0.33\times0.33\times1\times3\times1}=0.80$	0.128
Total	6.25	1.000

Table 4. 15: Normalized geometric mean of the sub-criteria with respect to 'Manufacturer'

Sub-criteria	Geometric mean	Normalized values
Integration	$\sqrt[5]{1\times3\times0.33\times1\times0.33}=0.80$	0.123
Supply-oriented capability	$\sqrt[5]{0.33\times1\times0.33\times0.2\times0.2}=0.34$	0.052
Customer demand-oriented capability	$\sqrt[5]{3\times3\times1\times1\times0.2}=1.12$	0.172
Information exchange capability	$\sqrt[5]{1\times5\times1\times1\times0.2}=1.00$	0.153
Time management and logistics cost capability	$\sqrt[5]{3\times5\times5\times5\times1}=3.27$	0.500
Total	6.54	1.000

Table 4. 16: Normalized geometric mean of the sub-criteria with respect to 'Distribution Centre'

Sub-criteria	Geometric mean	Normalized values
Integration	$\sqrt[5]{1\times1\times0.33\times0.33\times0.33}=0.42$	0.068
Supply-oriented capability	$\sqrt[5]{3\times1\times1\times0.33\times0.2}=0.72$	0.118
Customer demand-oriented capability	$\sqrt[5]{3\times1\times1\times0.2\times0.333}=0.72$	0.118
Information exchange capability	$\sqrt[5]{3\times3\times5\times1\times1}=2.14$	0.348
Time management and logistics cost capability	$\sqrt[5]{3\times5\times3\times1\times1}=2.14$	0.348
Total	6.15	1.000

Table 4. 17: Normalized geometric mean of the sub-criteria with respect to 'Retailer'

Sub-criteria	Geometric mean	Normalized values
Integration	$\sqrt[5]{1\times0.33\times0.33\times3\times3}=1.000$	0.159
Supply-oriented capability	$\sqrt[5]{3\times1\times3\times5\times3}=1.86$	0.297
Customer demand-oriented capability	$\sqrt[5]{3\times0.2\times1\times3\times5}=2.46$	0.392
Information exchange capability	$\sqrt[5]{0.33\times0.2\times0.33\times1\times0.33}=0.37$	0.060
Time management and logistics cost capability	$\sqrt[5]{0.33\times0.33\times0.2\times3\times1}=0.58$	0.093
Total	6.28	1.000

As given in Table 4.18, *Fractal information system integration* was the most important lower sub-criteria (0.373) followed by *standardization and simplification with respect* *to self-similarity and self-organisation* (0.227), *cross-functional unification with respect to self-similarity* (0.146), and both *structural adaptation with respect to self-organisation and dynamics*, and *compliance with respect to goal orientation*, with the lowest ranking (0.127) with respect to 'Integration'.

Table 4. 18: Normalized geometric mean of the lower sub criteria with respect to 'Integration'

Lower sub criteria	Geometric mean	Normalized values
Cross-functional unification with respect to self-similarity	$\sqrt[5]{1\times0.33\times1\times2\times0.5}$ =0.80	0.146
Standardization and simplification with respect to self-similarity and self-organisation	$\sqrt[5]{3\times1\times1\times2\times0.5}$=1.25	0.227
Structural adaptation with respect to self-organisation and dynamics	$\sqrt[5]{1\times1\times1\times0.5\times0.33}$=0.70	0.127
Compliance with respect to goal orientation	$\sqrt[5]{0.5\times0.5\times2\times1\times0.333}$=0.70	0.127
Fractal information system integration	$\sqrt[5]{2\times2\times3\times3\times1}$ =2.05	0.373
Total	5.49	1.000

Table 4.19 demonstrates that, with respect to 'Supply-oriented capability', *Supplier selection, relationship and involvement in the fractal supply network* was the most important lower sub-criteria (0.480) followed by s*elective distribution coverage with respect to goal orientation* (0.277) and both *Reverse logistics in the fractal supply network* and *operating across different businesses and different regions* attained the lowest ranking (0.122).

Table 4. 19: Normalized geometric mean of the lower sub-criteria with respect to "Supply-oriented capability"

Lower criteria	Geometric mean	Normalized values
Selective distribution coverage with respect to goal orientation	$\sqrt[4]{1\times0.33\times3\times3}$ =1.32	0.277
Supplier selection, relationship and involvement in the fractal supply network	$\sqrt[4]{3\times1\times3\times3}$=2.28	0.480
Reverse logistics in the fractal supply network	$\sqrt[4]{0.33\times0.33\times1\times1}$=0.58	0.122
Operating across different businesses and different regions	$\sqrt[4]{0.33\times0.33\times1\times1}$=0.0.58	0.122
Total	4.75	1.000

Table 4.20 indicates that, with respect to ‘Customer demand-oriented capability’, *customer service focus, with respect to goal orientation*, was the most important lower sub-criteria (0.493) followed by *output improvement of products or services* and *use of appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation* (0.195) and p*roduct or service reconfiguration for next lifecycle* attained the lowest ranking (0.116).

Table 4. 20: Normalized geometric mean of the lower sub-criteria with respect to "Customer demand-oriented capability"

Lower sub criteria	**Geometric mean**	**Normalized values**
Customer service focus with respect to goal orientation	$\sqrt[4]{1\times3\times3\times3}$ =2.28	0.493
Output improvement of products or services	$\sqrt[4]{0.33\times1\times2\times1}$=0.90	0.195
Product or service reconfiguration for next lifecycle	$\sqrt[4]{0.33\times0.5\times1\times0.5}$=0.54	0.116
Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation	$\sqrt[4]{0.33\times1\times2\times1}$=0.90	0.195
Total	4.62	1.000

Table 4.21 presents that, with respect to, the ‘Information exchange capability’, *use of a fractal paradigm in information systems development* was the most important lower sub-criteria (0.345) followed by *connectivity* (0.244) and both *development of appropriate information technology* and *information sharing* with the least ranking (0.205).

Table 4. 21: Normalized geometric mean of the lower sub-criteria with respect to ‘Information exchange capability’

Lower sub criteria	**Geometric mean**	**Normalized values**
Use a fractal paradigm in information systems development	$\sqrt[4]{1\times2\times2\times1}$ =1.41	0.345
Development of appropriate information technology	$\sqrt[4]{0.5\times1\times1\times1}$=0.84	0.205
Information sharing	$\sqrt[4]{0.5\times1\times1\times1}$=0.84	0.205
Connectivity	$\sqrt[4]{1\times1\times1\times1}$=1.000	0.244
Total	4.10	1.000

Table 4.22 shows that, with respect to, the 'Time management and logistics cost capability', *responsiveness to customer demand fluctuations* was the most important lower sub-criteria (0.382) followed by *logistics postponement and speculation* (0.290), *Inventory cost* (0.221) and *low total cost distribution* with the least ranking (0.107).

Table 4. 22: Normalized geometric mean of the lower sub-criteria with respect to 'Time management and logistics cost capability'

Lower sub criteria	**Geometric mean**	**Normalized values**
Logistics postponement and speculation	$\sqrt[4]{1\times1\times3\times1}=1.32$	0.290
Inventory cost	$\sqrt[4]{1\times1\times3\times0.33}=1.00$	0.221
Low total cost distribution	$\sqrt[4]{0.5\times0.33\times1\times0.33}=0.49$	0.107
Responsiveness to customer demand fluctuations	$\sqrt[4]{1\times3\times3\times1}=1.73$	0.382
Total	4.53	1.000

4.2.3.2. Applications of Eigenvector Method (EVM)

EVM is the original Saaty's approach to derive the priorities from the AHP method (see equation 4.3)

$$AX = \lambda_{max} X \qquad (4.3)$$

Where:

A= Comparison matrix

X= Priorities vector

λ_{max} = Maximal eigenvalue

In this study, Expert Choice Software was used which follows the EVM process to derive the priorities within the comparison matrices (see Figures 4.3-4.13) to satisfy and compare it with the outcome of the Normalised Geometric Mean (NGM) method. Moreover, the consistency of the comparison matrices is investigated through the use of Expert Choice.

The judgement of the five main criteria located in level two is entered. The conclusion was that *Manufacturer* was the most important criterion (manufacturer = 0.332) followed by *Supplier* (0.308), *Supply hub* (0.135), *Distribution Centre* (0.127) and *Retailer* with the least ranking (0.098). Moreover, the inconsistency rate of the main criteria matrix was 4%, less than the acceptable minimum rate of 10%. Therefore, the inconsistency level is acceptable, and the results show a high level of accuracy (see Figure 4.3). After comparing the major criteria, the sub-criteria and the lower sub-criteria were evaluated.

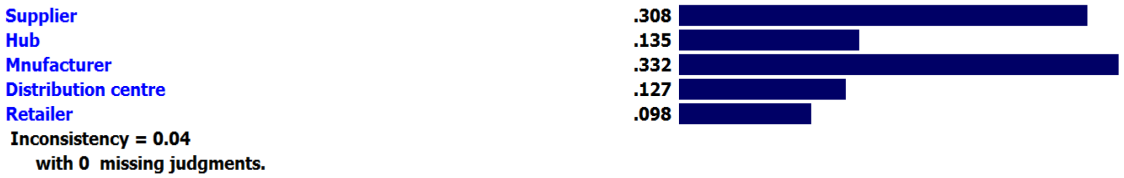


Figure 4. 3: Main criteria prioritization with respect to the main goal "A Fractal supply network logistics capability measurement" and inconsistency measurement

In accordance with sub-criteria, *Integration* was the most important sub-criteria (0.379) with respect to 'Supplier' (see Figure 4.4). However, with respect to 'Supply hub, Manufacturer, Distribution Centre and Retailer' *Supply-oriented capability* (0.423) (see Figure 4.5), *Time management and logistics cost capability* (0.506) (see Figure 4.6), both *Information exchange capability* and *Time management and logistics cost capability* (0.346) (see Figure 4.7), *Customer demand-oriented capability* (0.393) (see Figure 4.8), were the most important sub-criteria respectively. Moreover, the inconsistency rate of sub-criteria matrices with respect to "Supplier, Supplier Hub, Manufacturer, Distribution Centre and Retailer" is 5%, 8%, 9%, 8%, and 9%, respectively; all are less than 10%. Therefore, according to Saaty, the inconsistency level is acceptable and the results show the high level of accuracy.

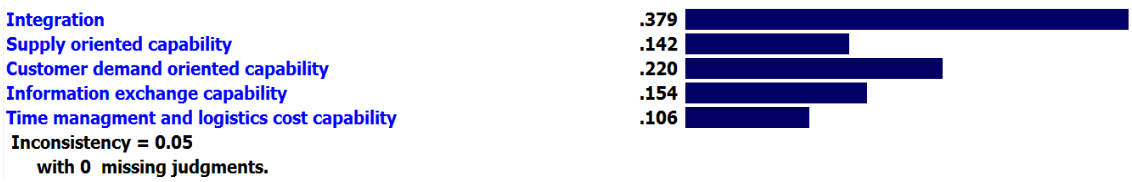


Figure 4. 4: Sub-criteria prioritization with respect to the "Supplier" and inconsistency measurement

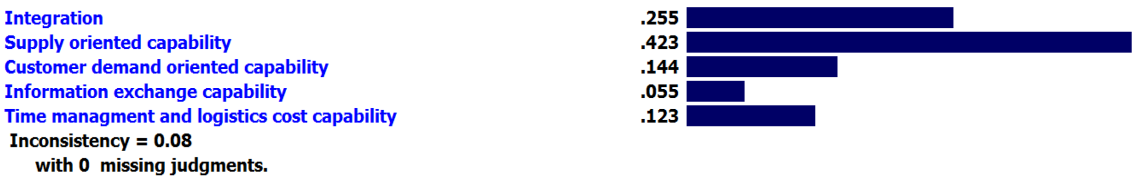


Figure 4. 5: Sub-criteria prioritization with respect to the " Supply hub" and inconsistency measurement

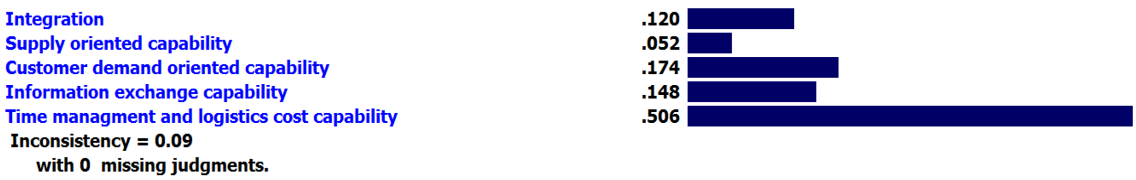


Figure 4. 6: Sub-criteria prioritization with respect to the "Manufacturer" and inconsistency measurement

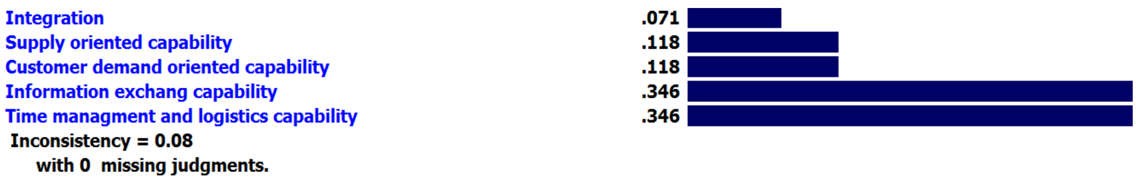


Figure 4. 7: Sub-criteria prioritization with respect to the "Distribution centre" and inconsistency measurement

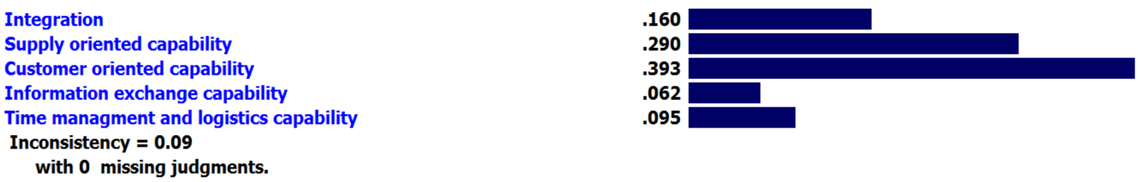


Figure 4. 8: Sub-criteria prioritization with respect to the "Retailer" and inconsistency measurement

As given in Figure 4.9, *The fractal information system integration* was the most important of the lower sub-criteria (0.356) followed by *Standardization and simplification with respect to self-similarity and self-organisation* (0.234), *Cross-functional unification with respect to self-similarity* (0.149), and both *Compliance with respect to goal orientation* and *Structural adaptation with respect to self-organisation and dynamics* were close behind (0.131 & 0.130), respectively, with respect to "Integration". Moreover, the inconsistency rate of lower sub criteria matrix with respect to "Integration" is 8%, less than 10%. Therefore, according to Saaty, the inconsistency level is acceptable, and the results show the high level of accuracy.

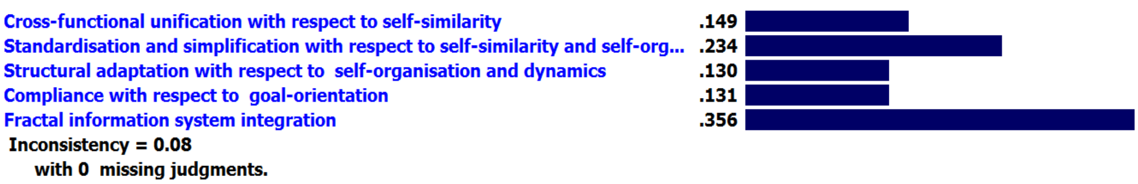


Figure 4. 9: Lower sub criteria prioritization with respect to the ‘Integration’ and inconsistency measurement

Figure 4.10 illustrates that with respect to ‘Supply-oriented capability’, *Supplier selection, relationship and involvement in the fractal supply network* was the most important of the lower sub-criteria (0.487) followed by *Selective distribution coverage with respect to goal orientation* (0.276) and both *Reverse logistics in the fractal supply network* and *Operating across different businesses and different regions* with the lowest ranking (0.118). Moreover, the inconsistency rate of the lower sub criteria matrix with respect to "Supply-oriented capability" is 6%, that is less than 10%. Therefore, according to Saaty, the inconsistency level is acceptable, and the results show the high level of accuracy.

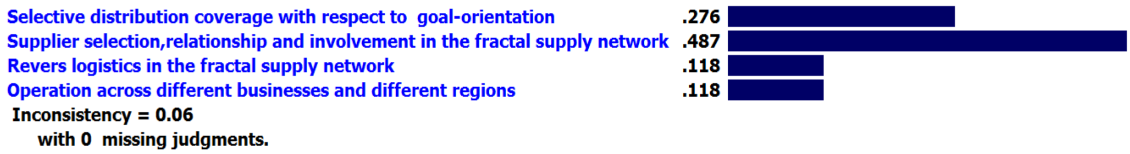


Figure 4. 10: Lower sub criteria prioritization with respect to the "Supply-oriented capability" and inconsistency measurement

Figure 4.11 demonstrates that with respect to "Customer demand-oriented capability", *Customer service focus with respect to goal orientation* was the most important of the lower sub-criteria (0.495) followed by *Output improvement of products or services* and *Use of appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation* (0.194) and *Product or service reconfiguration for next lifecycle* with the least ranking (0.117). Moreover, the inconsistency rate of the lower sub criteria matrix with respect to "Customer demand-oriented capability" is 2%, that is less than 10%. Therefore, according to Saaty, the inconsistency level is acceptable, and the results show the high level of accuracy.

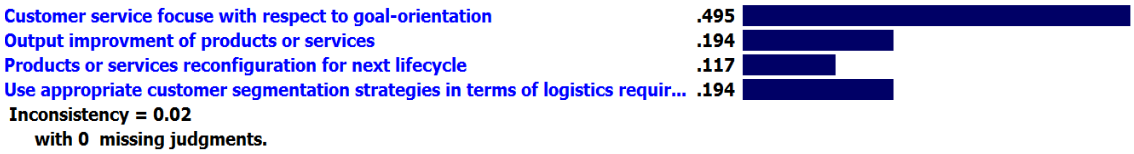


Figure 4. 11: Lower sub criteria prioritization with respect to the "Customer demand-oriented capability" and inconsistency measurement

Figure 4.12 shows that, with respect to the ‘Information exchange capability’, *Use of a fractal paradigm in information systems development* was the most important lower sub-criteria (0.347) followed by *Connectivity* (0.246) and both *Development of appropriate information technology* and *Information sharing* with the lowest ranking (0.204). Moreover, the inconsistency rates of lower sub criteria matrix, with respect to Information exchange capability’, is 2%, less than 10%. Therefore, according to Saaty, the inconsistency level is acceptable, and the results show the high level of accuracy.

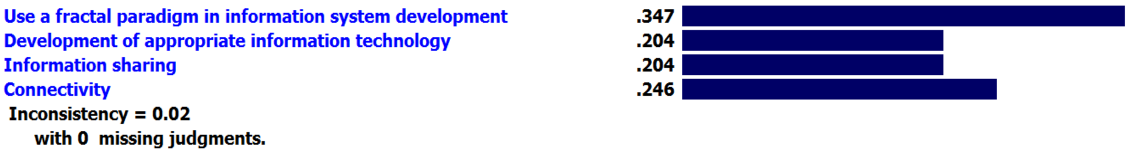


Figure 4. 12: Lower sub criteria prioritization with respect to the "Information exchange capability" and inconsistency measurement

Figure 4.13 proves that, with respect to the ‘Time management and logistics cost capability’, *Responsiveness to customer demand fluctuations* was the most important lower sub-criteria (0.394) followed by *Logistics postponement and speculation* (0.287), *Inventory cost* (0.223) and *Low total cost distribution with the least ranking* (0.96). Moreover, the inconsistency rate of the lower sub criteria matrix, with respect to ‘Time management and logistics cost capability’, is 6% and that is less than 10%. Therefore, according to Saaty, the inconsistency level is acceptable, and the results show the high level of accuracy.

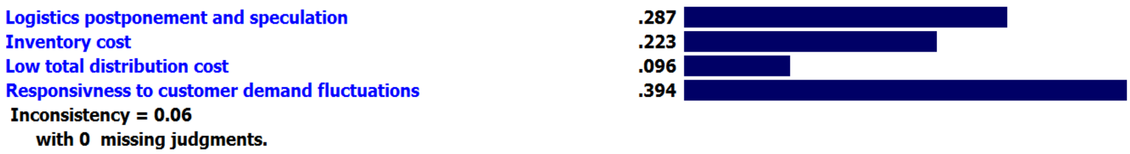


Figure 4. 13: Lower sub criteria prioritization with respect to the "Time management and logistics cost capability" and inconsistency measurement

4.2.4. Consistency

As already mentioned, consistency is the mechanism through which the validity of the pairwise comparisons are examined. In the geometric mean method, as an approximate method, instead of calculating the maximal eigenvalue (λmax) in equation (3.1), its approximate amount (L) is used within the following equation to satisfy and compare it with the outcome of the Expert Choice Software.

$$L = \frac{1}{n}\left[\sum_{i=1}^{n}\left(\frac{AX_i}{X_i}\right)\right] \qquad (4.4)$$

Where:

L= Approximate amount of maximal eigenvalue (λmax)

n= Dimension of the square matrix

X_i = Priorities vector

AX_i =The vector which is obtained by multiplying the comparison matrix (A) on Priorities vector (X)

In the following sections, the inconsistency measurement of main criteria, sub-criteria and lower sub criteria matrices are presented. In addition, in accordance with equation (3.2), overall inconsistency measurement is determined.

4.2.4.1. Inconsistency measurement of main criteria matrix with respect to the "Main Goal"

$$AX=\begin{bmatrix}1 & 3 & 1 & 2 & 3\\ 0.33 & 1 & 0.33 & 2 & 1\\ 1 & 3 & 1 & 3 & 3\\ 0.5 & 0.5 & 0.33 & 1 & 2\\ 0.33 & 1 & 0.33 & 0.5 & 1\end{bmatrix}\times\begin{bmatrix}0.31\\ 0.13\\ 0.34\\ 0.12\\ 0.1\end{bmatrix}=\begin{bmatrix}1.58\\ 0.69\\ 1.70\\ 0.65\\ 0.51\end{bmatrix}$$

$$L=\frac{1}{5}\left[\frac{1.58}{0.31}+\frac{0.69}{0.13}+\frac{1.70}{0.34}+\frac{0.65}{0.12}+\frac{0.51}{0.1}\right]=5.18$$

$$C.I=\frac{\text{L-n}}{\text{n-1}}=\frac{5.18-5}{5-1}=0.04$$

$$C.R=\frac{\text{C.I}}{\text{R.I}}=\frac{0.04}{1.12}=0.04$$

$$C.R\leq 0.1$$

4.2.4.2. Inconsistency measurement of the sub-criteria matrix with respect to the 'Supplier'

$$AX=\begin{bmatrix}1 & 3 & 3 & 2 & 2\\ 0.33 & 1 & 0.5 & 1 & 2\\ 0.33 & 2 & 1 & 2 & 2\\ 0.5 & 1 & 0.5 & 1 & 2\\ 0.5 & 0.5 & 0.5 & 0.5 & 1\end{bmatrix}\times\begin{bmatrix}0.37\\ 0.15\\ 0.22\\ 0.16\\ 0.10\end{bmatrix}=\begin{bmatrix}2\\ 0.75\\ 1.16\\ 0.81\\ 0.55\end{bmatrix}$$

$$L=\frac{1}{5}\left[\frac{2}{0.37}+\frac{0.75}{0.15}+\frac{1.16}{0.22}+\frac{0.81}{0.16}+\frac{0.55}{0.1}\right]=5.23$$

$$C.I=\frac{L-n}{n-1}=\frac{5.23-5}{5-1}=0.06$$

$$C.R=\frac{C.I}{R.I}=\frac{0.06}{1.12}=0.05$$

$$C.R\leq 0.1$$

4.2.4.3. Inconsistency measurement of the sub-criteria matrix with respect to 'Supply hub'

$$AX=\begin{bmatrix} 1 & 0.33 & 3 & 3 & 3 \\ 3 & 1 & 3 & 5 & 3 \\ 0.33 & 0.33 & 1 & 5 & 1 \\ 0.33 & 0.2 & 0.2 & 1 & 0.33 \\ 0.33 & 0.33 & 1 & 3 & 1 \end{bmatrix} \times \begin{bmatrix} 0.25 \\ 0.43 \\ 0.14 \\ 0.05 \\ 0.13 \end{bmatrix} = \begin{bmatrix} 1.36 \\ 2.25 \\ 0.77 \\ 0.29 \\ 0.66 \end{bmatrix}$$

$$L=\frac{1}{5}\left[\frac{1.36}{0.25}+\frac{2.25}{0.43}+\frac{0.77}{0.14}+\frac{0.29}{0.05}+\frac{0.66}{0.13}\right] = 5.34$$

$$C.I=\frac{\text{L-n}}{\text{n-1}}=\frac{5.34\text{-}5}{5\text{-}1}=0.09$$

$$C.R=\frac{\text{C.I}}{\text{R.I}}=\frac{0.09}{1.12}=0.08$$

$$C.R \le 0.1$$

4.2.4.4. Inconsistency measurement of the sub-criteria matrix with respect to 'Manufacturer'

$$AX=\begin{bmatrix} 1 & 3 & 0.33 & 1 & 0.33 \\ 0.33 & 1 & 0.33 & 0.2 & 0.2 \\ 3 & 3 & 1 & 1 & 0.2 \\ 1 & 5 & 1 & 1 & 0.2 \\ 3 & 5 & 5 & 5 & 1 \end{bmatrix} \times \begin{bmatrix} 0.12 \\ 0.05 \\ 0.17 \\ 0.15 \\ 0.50 \end{bmatrix} = \begin{bmatrix} 0.66 \\ 0.28 \\ 0.95 \\ 0.81 \\ 2.75 \end{bmatrix}$$

$$L=\frac{1}{5}\left[\frac{0.66}{0.12}+\frac{0.28}{0.05}+\frac{0.95}{0.17}+\frac{0.81}{0.15}+\frac{2.75}{0.5}\right]=5.41$$

$$C.I=\frac{L-n}{n-1}=\frac{5.41\text{-}5}{5\text{-}1}=0.10$$

$$C.R=\frac{C.I}{R.I}=\frac{0.10}{1.12}=0.09$$

$$C.R \le 0.1$$

4.2.4.5. Inconsistency measurement of the sub-criteria matrix with respect to 'Distribution Centre'

$$AX=\begin{bmatrix}1 & 0.33 & 0.33 & 0.33 & 0.33\\ 3 & 1 & 1 & 0.33 & 0.2\\ 3 & 1 & 1 & 0.2 & 0.33\\ 3 & 3 & 5 & 1 & 1\\ 3 & 5 & 3 & 1 & 1\end{bmatrix}\times\begin{bmatrix}0.07\\0.12\\0.12\\0.35\\0.35\end{bmatrix}=\begin{bmatrix}0.38\\0.63\\0.63\\1.84\\1.84\end{bmatrix}$$

$$L=\frac{1}{5}\left[\frac{0.38}{0.07}+\frac{0.63}{0.12}+\frac{0.63}{0.12}+\frac{1.84}{0.35}+\frac{1.84}{0.35}\right]=5.35$$

$$C.I=\frac{\text{L-n}}{\text{n-1}}=\frac{5.35-5}{\text{5-1}}=0.09$$

$$C.R=\frac{\text{C.I}}{\text{R.I}}=\frac{0.09}{1.12}=0.08$$

$$C.R\leq 0.1$$

4.2.4.6. Inconsistency measurement of the sub-criteria matrix with respect to 'Retailer'

$$AX=\begin{bmatrix}1 & 0.33 & 0.33 & 3 & 3\\ 3 & 1 & 0.5 & 5 & 3\\ 3 & 2 & 1 & 3 & 5\\ 0.33 & 0.2 & 0.33 & 1 & 0.33\\ 0.33 & 033 & 0.2 & 3 & 1\end{bmatrix}\times\begin{bmatrix}0.16\\0.30\\0.39\\0.06\\0.09\end{bmatrix}=\begin{bmatrix}0.85\\1.55\\2.11\\0.33\\0.50\end{bmatrix}$$

$$L=\frac{1}{5}\left[\frac{0.85}{0.16}+\frac{1.55}{0.30}+\frac{2.11}{0.39}+\frac{0.33}{0.06}+\frac{0.5}{0.09}\right]=5.38$$

$$C.I=\frac{L-n}{n-1}=\frac{5.38-5}{\text{5-1}}=0.10$$

$$C.R=\frac{C.I}{R.I}=\frac{0.10}{1.12}=0.09$$

$$C.R\leq 0.1$$

4.2.4.7. Inconsistency measurement of lower sub criteria matrix with respect to 'Integration'

$$AX = \begin{bmatrix} 1 & 0.33 & 1 & 2 & 0.5 \\ 3 & 1 & 1 & 2 & 0.5 \\ 1 & 1 & 1 & 0.5 & 0.33 \\ 0.5 & 0.5 & 2 & 1 & 0.33 \\ 2 & 2 & 3 & 3 & 1 \end{bmatrix} \times \begin{bmatrix} 0.15 \\ 0.23 \\ 0.13 \\ 0.13 \\ 0.37 \end{bmatrix} = \begin{bmatrix} 0.79 \\ 1.23 \\ 0.69 \\ 0.69 \\ 1.88 \end{bmatrix}$$

$$L = \frac{1}{5}\left[\frac{0.79}{0.15} + \frac{1.23}{0.23} + \frac{0.69}{0.13} + \frac{0.69}{0.13} + \frac{1.88}{0.37}\right] = 5.35$$

$$C.I = \frac{L-n}{n-1} = \frac{5.35-5}{5\text{-}1} = 0.09$$

$$C.R = \frac{C.I}{R.I} = \frac{0.09}{1.12} = 0.08$$

$C.R \leq 0.1$

4.2.4.8. Inconsistency measurement of lower sub criteria matrix with respect to 'Supply-oriented capability'

$$AX = \begin{bmatrix} 1 & 0.33 & 3 & 3 \\ 3 & 1 & 3 & 3 \\ 0.33 & 0.33 & 1 & 1 \\ 0.33 & 0.33 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} 0.28 \\ 0.48 \\ 0.12 \\ 0.12 \end{bmatrix} = \begin{bmatrix} 1.17 \\ 2.04 \\ 0.5 \\ 0.5 \end{bmatrix}$$

$$L = \frac{1}{4}\left[\frac{1.17}{0.28} + \frac{2.04}{0.48} + \frac{0.5}{0.12} + \frac{0.5}{0.12}\right] = 4.15$$

$$C.I = \frac{L-n}{n-1} = \frac{4.15-4}{4\text{-}1} = 0.5$$

$$C.R = \frac{C.I}{R.I} = \frac{0.05}{0.9} = 0.06$$

$C.R \leq 0.1$

4.2.4.9. Inconsistency measurement of lower sub criteria matrix with respect to 'Customer demand-oriented capability'

$$AX=\begin{bmatrix} 1 & 3 & 3 & 3 \\ 0.33 & 1 & 2 & 1 \\ 0.33 & 0.5 & 1 & 0.5 \\ 0.398 & 1 & 2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.49 \\ 0.20 \\ 0.12 \\ 0.20 \end{bmatrix} = \begin{bmatrix} 2.01 \\ 0.79 \\ 0.48 \\ 0.79 \end{bmatrix}$$

$$L=\frac{1}{4}\left[\frac{2.01}{0.49}+\frac{0.79}{0.20}+\frac{0.48}{0.12}+\frac{0.79}{0.20}\right]=4.06$$

$$C.I=\frac{L-n}{n-1}=\frac{4.06-4}{4\text{-}1}=0.02$$

$$C.R=\frac{C.I}{R.I}=\frac{0.02}{0.9}=0.02$$

$C.R \le 0.1$

4.2.4.10. Inconsistency measurement of lower sub criteria matrix with respect to 'Information exchange capability'

$$AX=\begin{bmatrix} 1 & 2 & 2 & 1 \\ 0.5 & 1 & 1 & 1 \\ 0.5 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} 0.35 \\ 0.21 \\ 0.21 \\ 0.24 \end{bmatrix} = \begin{bmatrix} 1.41 \\ 0.83 \\ 0.83 \\ 1 \end{bmatrix}$$

$$L=\frac{1}{4}\left[\frac{1.41}{0.35}+\frac{0.83}{0.21}+\frac{0.83}{0.21}+\frac{1}{0.24}\right]=4.06$$

$$C.I=\frac{L-n}{n-1}=\frac{4.06-4}{4\text{-}1}=0.02$$

$$C.R=\frac{C.I}{R.I}=\frac{0.02}{0.9}=0.02$$

$C.R \le 0.1$

4.2.4.11. Inconsistency measurement of lower sub criteria matrix with respect to 'Time management and logistics cost capability'

$$AX=\begin{bmatrix} 1 & 1 & 3 & 1 \\ 1 & 1 & 3 & 0.33 \\ 0.33 & 0.33 & 1 & 0.33 \\ 1 & 3 & 3 & 1 \end{bmatrix} \times \begin{bmatrix} 0.29 \\ 0.22 \\ 0.11 \\ 0.38 \end{bmatrix} = \begin{bmatrix} 1.21 \\ 0.96 \\ 0.40 \\ 1.66 \end{bmatrix}$$

$$L=\frac{1}{4}\left[\frac{1.21}{0.29}+\frac{0.96}{0.22}+\frac{0.40}{0.11}+\frac{1.66}{0.38}\right]=4.16$$

$$C.I=\frac{\text{L-n}}{\text{n-1}}=\frac{4.16-4}{\text{4-1}}=0.05$$

$$C.R=\frac{\text{C.I}}{\text{R.I}}=\frac{0.05}{0.9}=0.06$$

$$C.R \leq 0.1$$

4.2.4.12. Overall Inconsistency measurement

$$C.R=\frac{0.71}{11.44}=0.06$$

4.2.5. Synthesizing the results

After deriving the local priorities for the criteria, sub-criteria and lower sub criteria through pairwise comparisons, the synthesis analysis has been completed to understand the global priorities of lower sub criteria towards the main goal and each main criterion (see equations 4.5 and 4.6).

$$G_{SG} = \sum_{k=1}^{n}\sum_{i=1}^{m} W_k \times W_i \times W_{i\,j} \tag{4.5}$$

Where:

G_{SG}= Global priorities of the lower sub-criteria with respect to the main goal

W_k = Local weight of main criteria k.

W_i = Local weight of sub-criteria i.

W_{ij} = Local weight of the lower sub-criteria with respect to the sub-criteria i.

$$G_{SM} = \sum_{i=1}^{n} w_i \times w_{ij} \tag{4.6}$$

Where:

G_{SM}= Global priorities of the lower sub-criteria with respect to the main criteria

4.2.5.1. Global priorities of all lower sub-criteria with respect to the "Main Goal"

As shown in figure 4.14, *Responsiveness to customer demand fluctuations* received the highest ranking (NGM=10.3% & EVM=10.7 %), followed by *Customer service focus with respect to goal orientation* (NGM=9.8% & EVM=9.8%), *Supplier selection, relationship and involvement in the fractal supply network* (NGM=7.8% & EVM 7.9%) and both *Reverse logistics in the fractal supply network* and O*perating across different businesses and different regions* (NGM=2% & EVM=1.9 %) were the lowest ranking with respect to the 'Main Goal'.

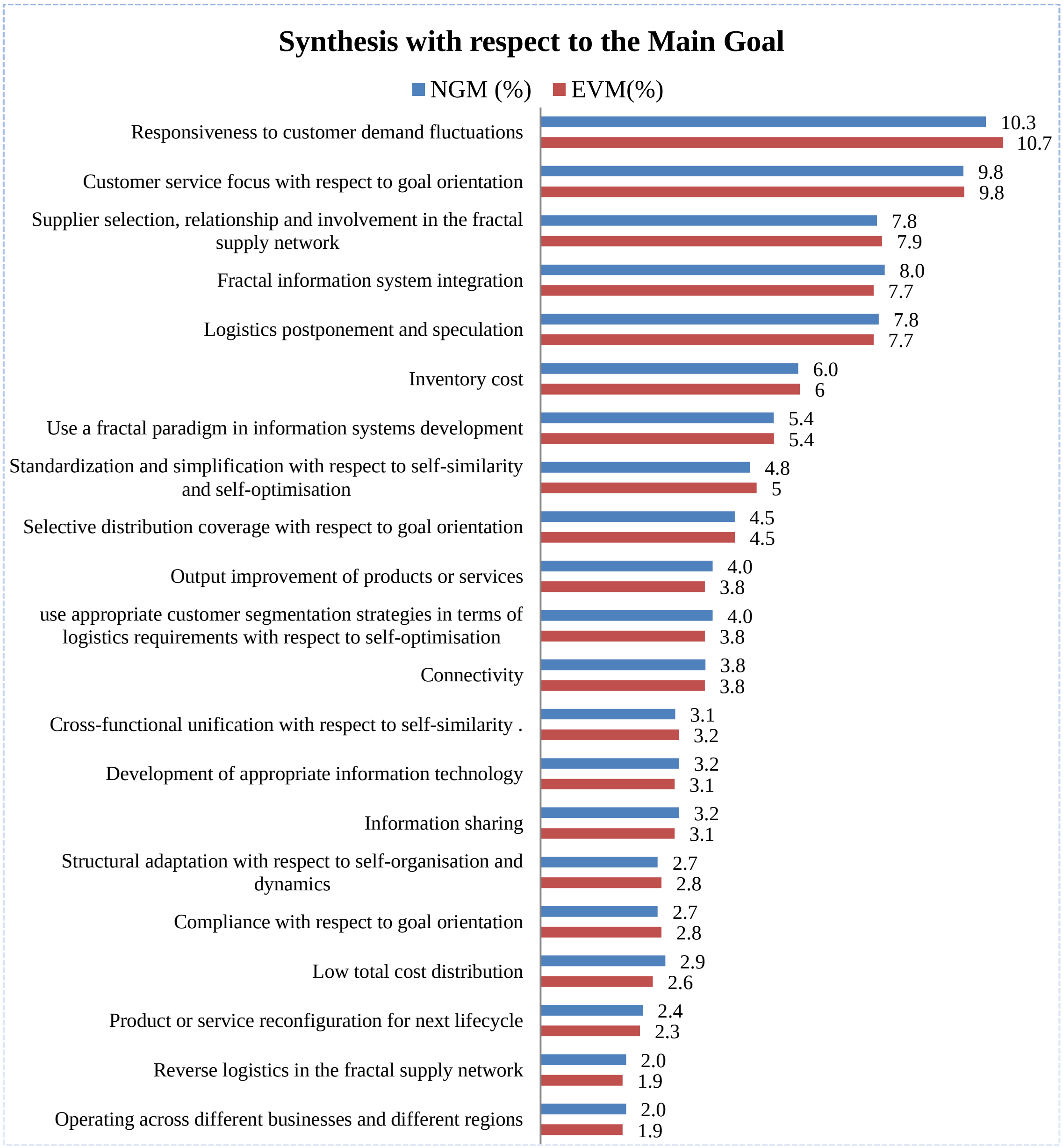


Figure 4. 14: Synthesis with respect to Main Goal: A Fractal supply network logistics capability measurement (AHP)

4.2.5.2. Global priorities of all lower sub-criteria with respect to the "Supplier"

Figure 4.15 illustrates that, with respect to the 'Supplier', *Fractal information system integration* was the most important of the lower sub-criteria with (NGM=13.8% & EVM=13.5%), followed by *Customer service focus, with respect to goal orientation,* with (NGM=10.9% & EVM=10.9%), *Standardization and simplification, with respect to self-similarity and self-organisation*, with (NGM=8.4% & EVM=8.9%) and *Low total cost distribution* with (NGM=1.1% & EVM=1%) was the lowest ranked.

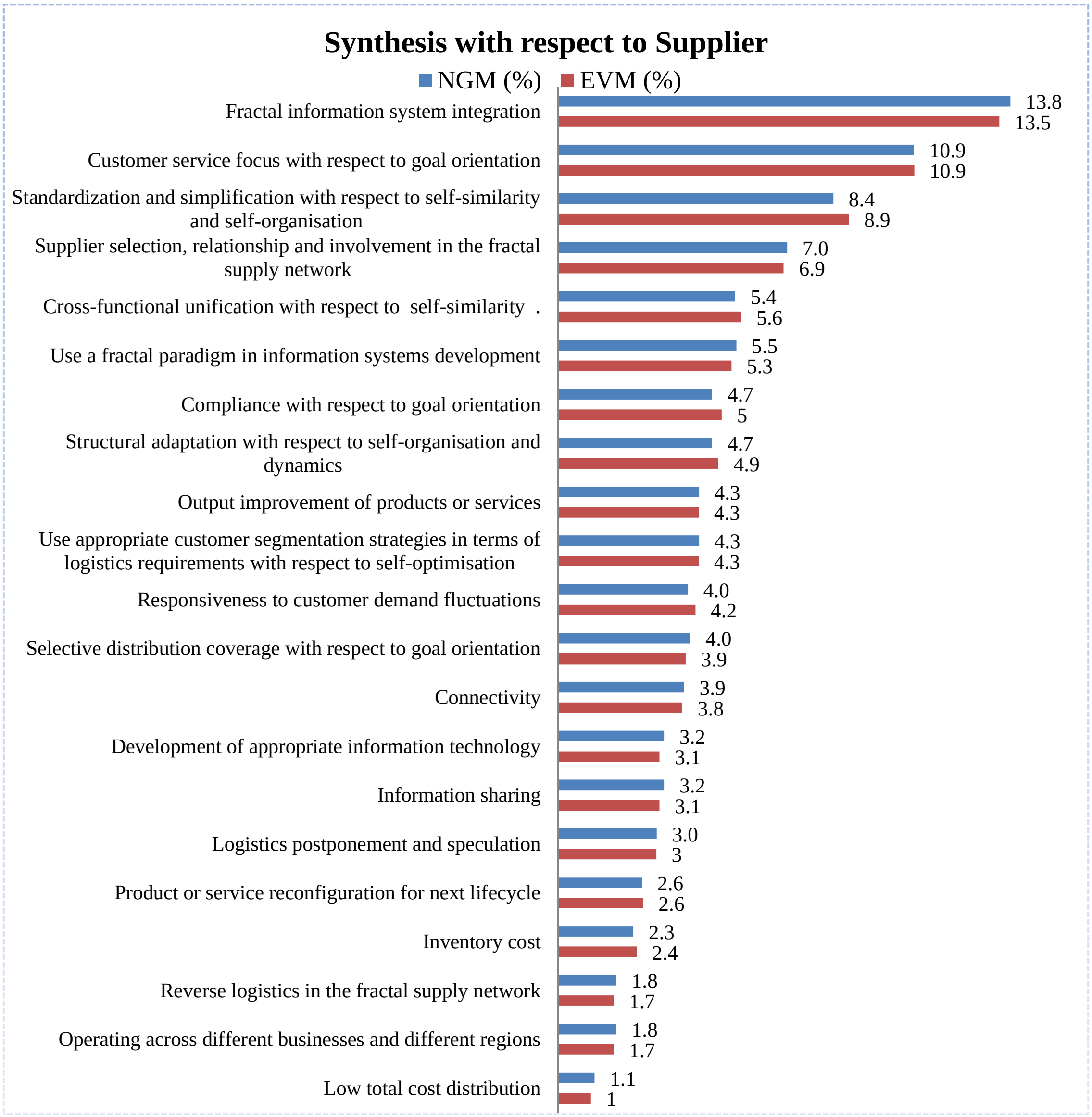


Figure 4. 15: Synthesis with respect to Supplier (AHP)

4.2.5.3. Global priorities of all lower sub-criteria with respect to the "Supply hub"

With respect to the "Supply Hub", *Supplier selection, relationship and involvement in the fractal supply network* was the most important lower sub-criteria with (NGM=20.5% & EVM=20.6%), followed by *Selective distribution coverage, with respect to goal orientation*, with (NGM=11.8% & EVM=11.7%), *Fractal information system integration* with (NGM=9.3% & EVM=9.1%) and both *Development of appropriate information technology* and *Information sharing* with (NGM=1.1% & EVM=1.1%) were the lowest ranked (see Figure 4.16).

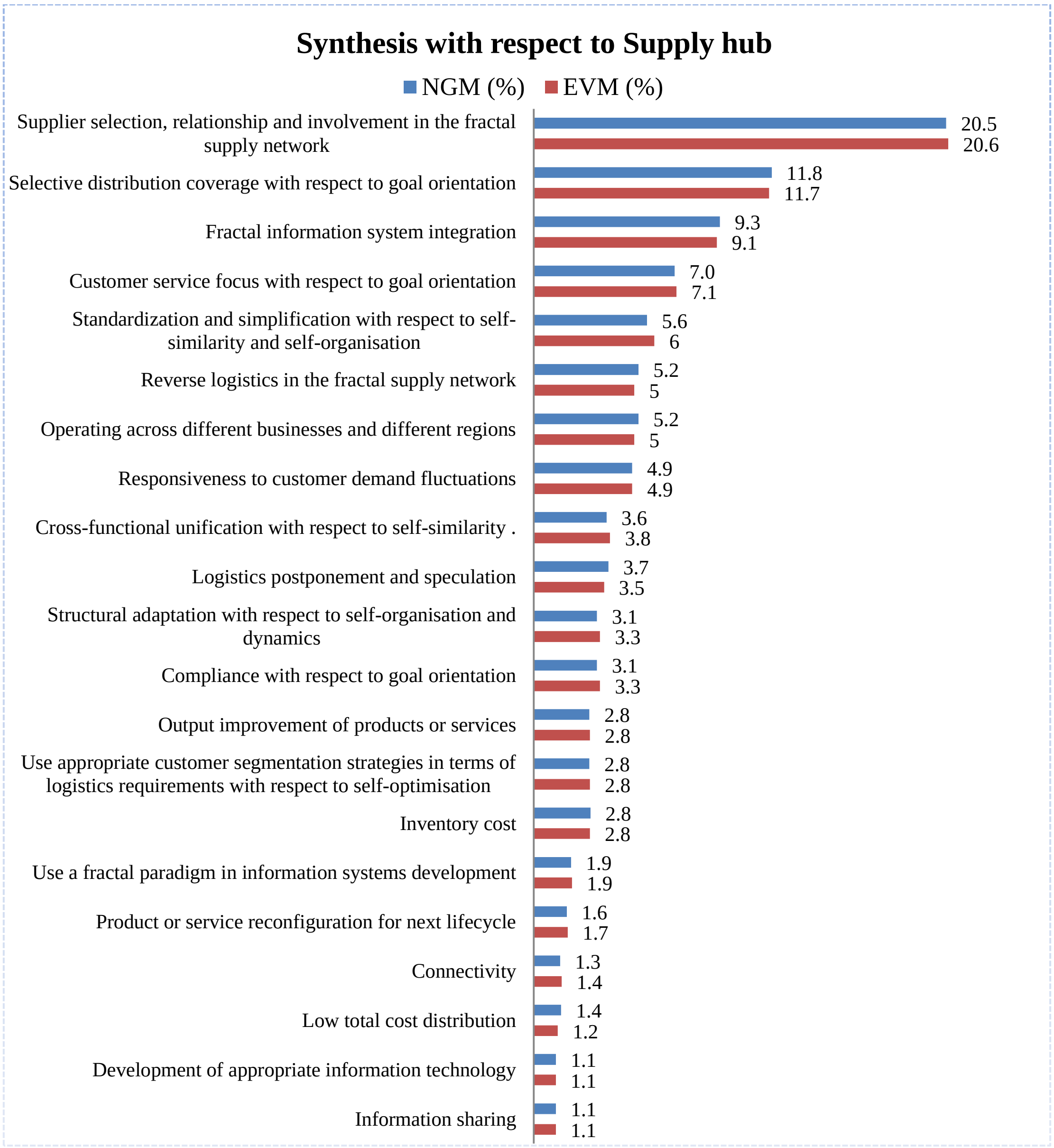


Figure 4. 16: Synthesis with respect to the Supply hub (AHP)

4.2.5.4. Global priorities of all lower sub criteria with respect to the "Manufacturer"

As given in Figure 4.17, with respect to the 'Manufacturer', *Responsiveness to customer demand fluctuations* was the most important of the lower sub-criteria with (NGM=19.13% & EVM=19.9%), followed by *Logistics postponement and speculation* with (NGM=14.5% & EVM=14.5 %), *Inventory cost* with (NGM=11.1% & EVM=11.3%) and both *Reverse logistics in the fractal supply network* and *Operating across different businesses and different regions* were the lowest ranked (NGM=0.6% & EVM=0.6 %).

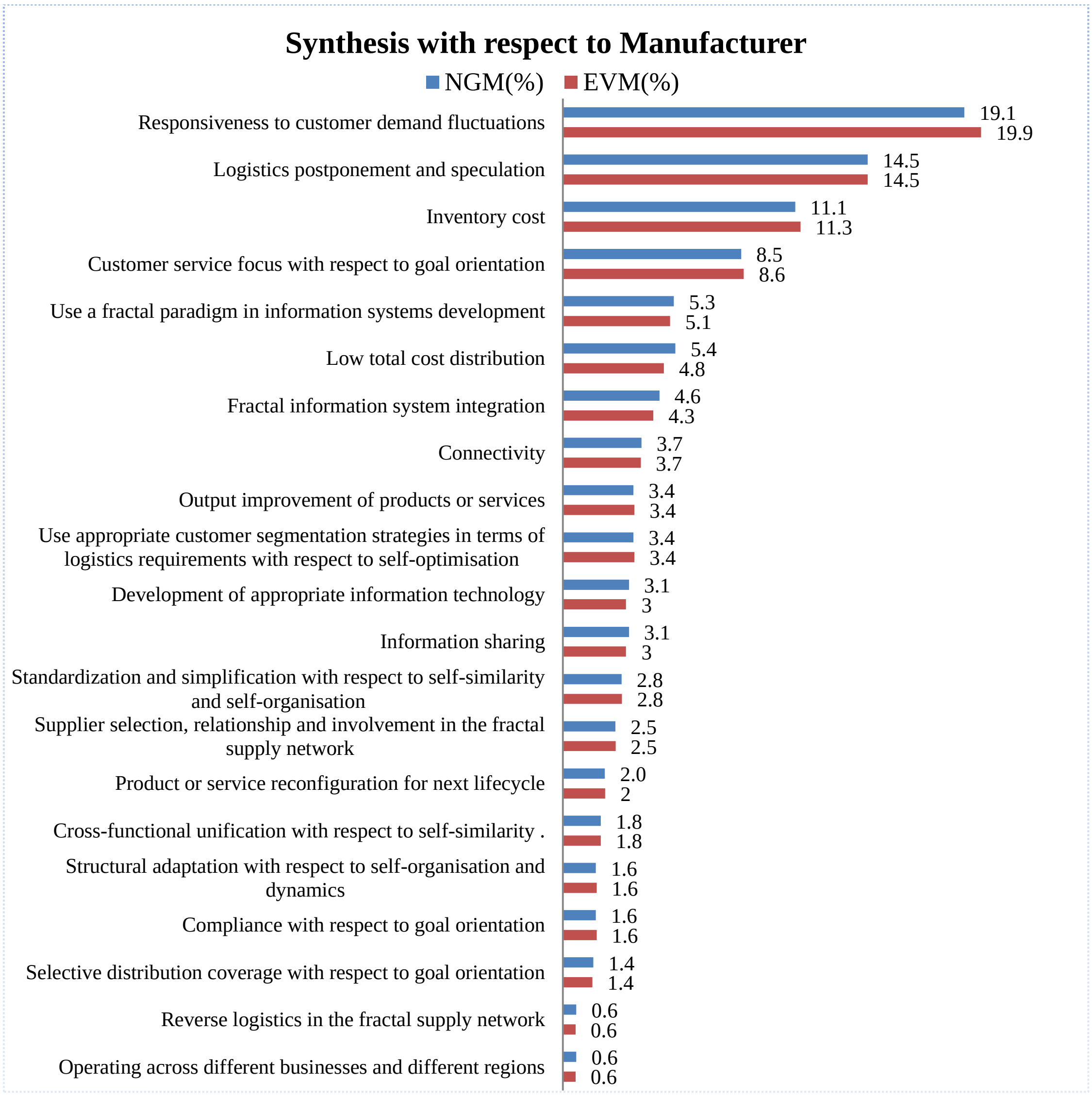


Figure 4. 17: Synthesis with respect to Manufacturer (AHP)

4.2.5.5. Global priorities of all lower sub-criteria with respect to the 'Distribution Centre'

Figure 4.18 indicates that with respect to the 'Distribution Centre', *Responsiveness to customer demand fluctuations* was the most important lower sub-criteria with (NGM=13.3% & EVM=13.6%), followed by *Use a fractal paradigm in information systems development* with (NGM=12% & EVM =12%), *Logistics postponement and speculation* with (NGM=10.1% & EVM=9.9%) and both S*tructural adaptation with respect to self-organisation and dynamics* and *Compliance, with respect to goal orientation*, (NGM=0.9%, EVM=0.9%) was the lowest ranked.

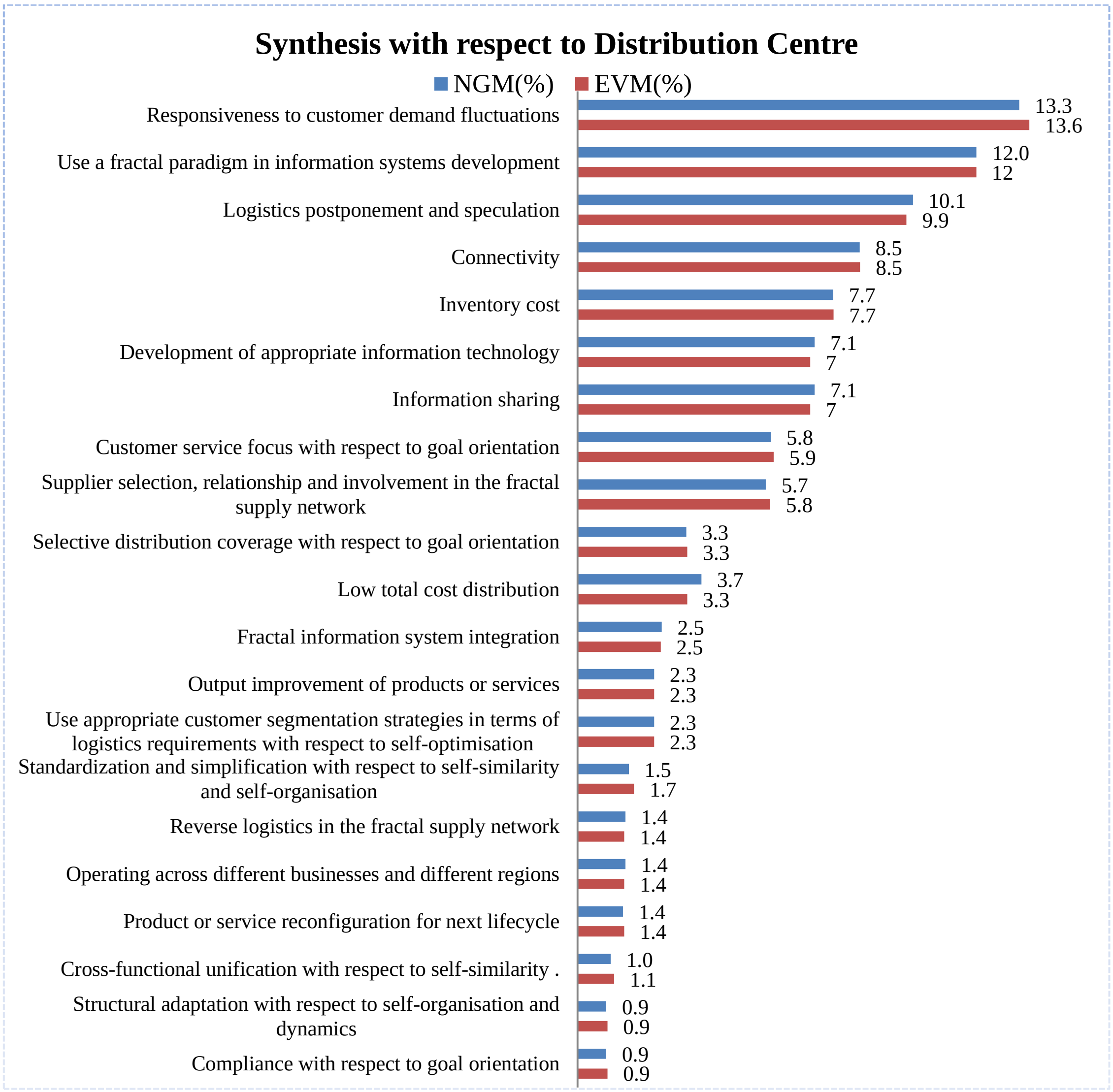


Figure 4. 18: Synthesis with respect to Distribution Centre (AHP)

4.2.5.6. Global priorities of all lower sub-criteria with respect to the 'Retailer'

Figure 4.19 shows that, with respect to, the 'Retailer', the *Customer service focus, with respect to goal orientation*, was the most important of the lower sub criteria with (NGM=19.3% & EVM=19.4%), followed by *Supplier selection, relationship and involvement in the fractal supply network* with (NGM=14.3% & EVM=14.1%), *Selective distribution coverage with respect to goal orientation* with (NGM=8.2% & EVM=8%) and both *Development of appropriate information technology* and *Low total cost distribution* (NGM=1% & EVM=0.9%) achieved the lowest ranking.

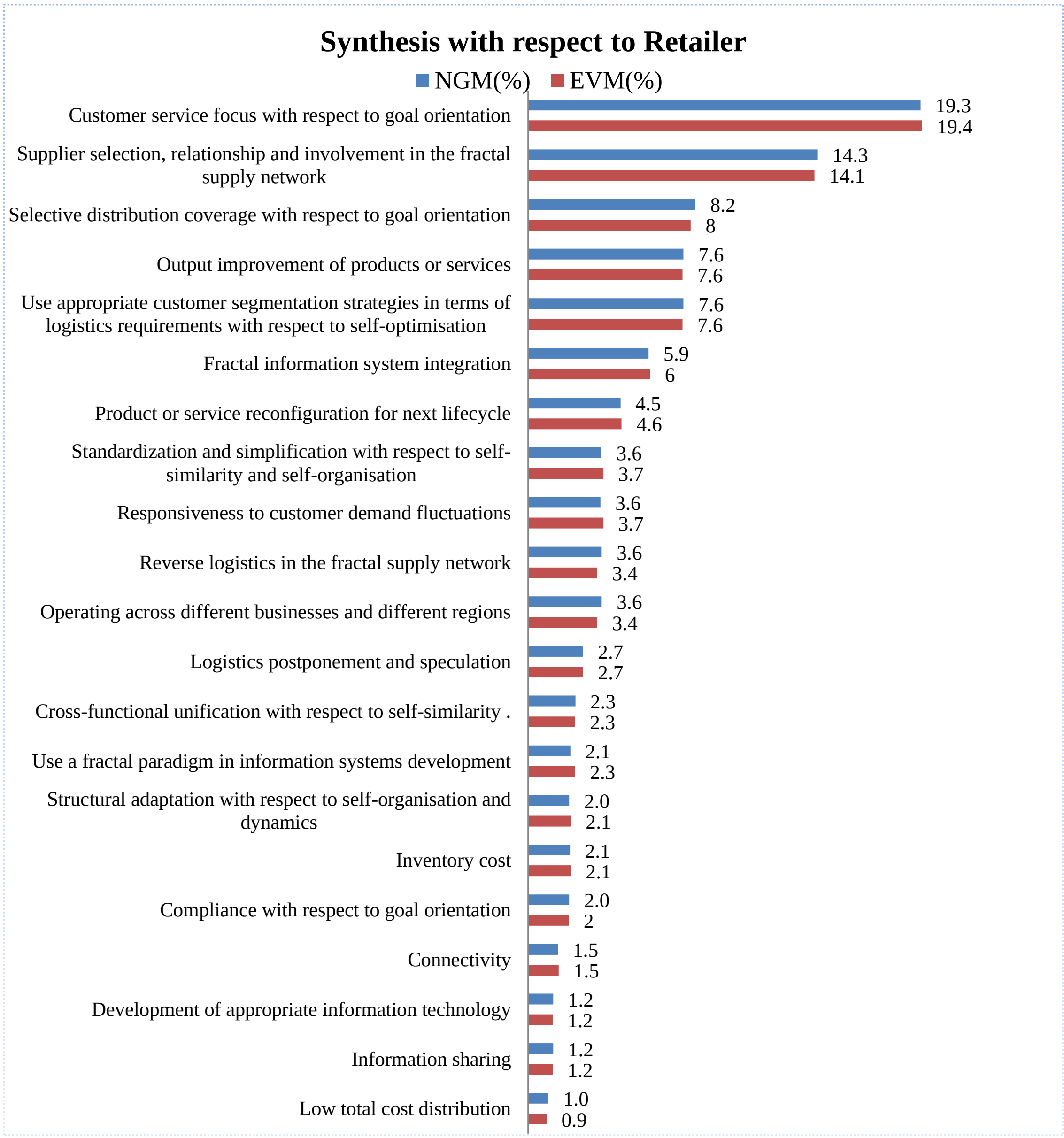


Figure 4. 19: Synthesis with respect to Retailer (AHP)

4.3. Application of Fuzzy-AHP

In this section, the work carried out using Fuzzy-AHP for evaluating the priority of the main criteria, sub-criteria and the lower sub-criteria in the fractal supply network is explained.

4.3.1. Converting the AHP comparisons matrices into Fuzzy comparisons matrices

In this section, the AHP matrix is converted into the fuzzy matrix using the fuzzy conversion scale (see Table 3.3). Tables 4.23-4.33 present the converted matrix using TFN for the main criteria, sub-criteria and lower sub-criteria.

Table 4. 23: Fuzzy comparison matrix with respect to the 'Main Goal'

	Supplier	**Supply Hub**	**Manufacturer**	**Distribution centre**	**Retailer**
Supplier	(1,1,1)	(1,3,5)	(1,1,1)	(1,2,4)	(1,3,5)
Supply hub	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)	(1,2,4)	(1,1,1)
Manufacture	(1,1,1)	(1,3,5)	(1,1,1)	(1,3,5)	(1,3,5)
Distribution centre	(1/4,1/2,1/1)	(1/4,1/2,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1,2,4)
Retailer	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)	(1/4,1/2,1/1)	(1,1,1)

Table 4. 24: Fuzzy comparison matrix of sub-criteria with respect to the 'Supplier'

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	(1,1,1)	(1,3, 5)	(1,3, 5)	(1,2, 4)	(1,2, 4)
Supply-oriented capability	(1/5, 1/3, 1/1)	(1,1,1)	(1/4, 1/2, 1/1)	(1,1,1)	(1,2, 4)
Customer demand-oriented capability	(1/5, 1/3, 1/1)	(1,2, 4)	(1,1,1)	(1,2, 4)	(1,2, 4)
Information exchange capability	(1/4, 1/2, 1/1)	(1,1,1)	(1/4, 1/2, 1/1)	(1,1,1)	(1,2, 4)
Time management and logistics cost capability	(1/4, 1/2, 1/1)	(1/4, 1/2, 1/1)	(1/4, 1/2, 1/1)	(1/4, 1/2, 1/1)	(1,1,1)

Table 4. 25: Fuzzy comparison matrix of sub-criteria with respect to the 'Supply hub'

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	(1,1,1)	(1/5,1/3,1/1)	(1,3, 5)	(1,3, 5)	(1,3, 5)
Supply-oriented capability	(1,3, 5)	(1,1,1)	(1,3, 5)	(3,5,7)	(1,3, 5)
Customer demand-oriented capability	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)	(3,5,7)	(1,1,1)
Information exchange capability	(1/5,1/3,1/1)	(1/7,1/5, 1/3)	(1/7,1/5, 1/3)	(1,1,1)	(1/5,1/3,1/1)
Time management and logistics cost capability	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1,3, 5)	(1,1,1)

Table 4. 26: Fuzzy comparison matrix of sub-criteria with respect to the 'Manufacturer'

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	(1,1,1)	(1,3,5)	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)
Supply-oriented capability	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)
Customer demand-oriented capability	(1,3,5)	(1,3,5)	(1,1,1)	(1,1,1)	(1/7,1/5,1/3)
Information exchange capability	(1,1,1)	(3,5,7)	(1,1,1)	(1,1,1)	(1/7,1/5,1/3)
Time management and logistics cost capability	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,1)

Table 4. 27: Fuzzy comparison matrix of sub-criteria with respect to the 'Distribution centre'

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	(1,1,1)	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1/5,1/3,1/1)
Supply-oriented capability	(1,3,5)	(1,1,1)	(1,1,1)	(1/5,1/3,1/1)	(1/7,1/5,1/3)
Customer demand-oriented capability	(1,3,5)	(1/1,1/1,1/1)	(1,1,1)	(1/7,1/5,1/3)	(1/5,1/3,1/1)
Information exchange capability	(1,3,5)	(1,3,5)	(3,5,7)	(1,1,1)	(1,1,1)
Time managemen t and logistics cost capability	(1,3,5)	(3,5,7)	(1,3,5)	(1/1,1/1,1/1)	(1,1,1)

Table 4. 28: Fuzzy comparison matrix of sub-criteria with respect to the 'Retailer'

	Integration	**Supply-oriented capability**	**Customer demand-oriented capability**	**Information exchange capability**	**Time management and logistics cost capability**
Integration	(1,1,1)	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,3,5)	(1,3,5)
Supply-oriented capability	(1,3,5)	(1,1,1)	(1/4,1/2,1/1)	(3,5,7)	(1,3,5)
Customer demand-oriented capability	(1,3,5)	(1,2,4)	(1,1,1)	(1,3,5)	(3,5,7)
Information exchange capability	(1/5,1/3,1/1)	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)
Time managemen t and logistics cost capability	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)

Table 4. 29: Fuzzy comparison matrix of lower sub-criteria with respect to the 'Integration'

	Cross-functional unification with respect to self-similarity	**Standardization and simplification with respect to self-similarity and self-organisation**	**Structural adaptation with respect to self-organisation and dynamics**	**Compliance with respect to goal orientation**	**Fractal information system integration**
Cross-functional unification with respect to self-similarity	(1,1,1)	(1/5,1/3,1/1)	(1,1,1)	(1,2,4)	(1/4,1/2,1/1)
Standardization and simplification with respect to self-similarity and self-organisation	(1,3,5)	(1,1,1)	(1,1,1)	(1,2,4)	(1/4,1/2,1/1)
Structural adaptation with respect to self-organisation and dynamics	(1/1,1/1,1/1)	(1/1,1/1,1/1)	(1,1,1)	(1/4,1/2,1/1)	(1/5,1/3,1/1)
Compliance with respect to goal orientation	(1/4,1/2,1/1)	(1/4,1/2,1/1)	(1,2,4)	(1,1,1)	(1/5,1/3,1/1)
Fractal information system integration	(1,2,4)	(1,2,4)	(1,3,5)	(1,3,5)	(1,1,1)

Table 4. 30: Fuzzy comparison matrix of lower sub-criteria with respect to the 'Supply-oriented capability'

	Selective distribution coverage with respect to goal orientation	**Supplier selection, relationship and involvement in the fractal supply network**	**Reverse logistics in the fractal supply network**	**Operating across different businesses and different regions**
Selective distribution coverage with respect to goal orientation	(1,1,1)	(1/5,1/3,1/1)	(1,3,5)	(1,3,5)
Supplier selection, relationship and involvement in the fractal supply network	(1,3,5)	(1,1,1)	(1,3,5)	(1,3,5)
Reverse logistics in the fractal supply network	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1,1,1)
Operating across different businesses and different regions	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1/1,1/1,1/1)	(1,1,1)

Table 4. 31: Fuzzy comparison matrix of lower sub-criteria with respect to the "Customer demand-oriented capability"

	Customer service focus with respect to goal orientation	**Output improvement of products or services**	**Product or service reconfiguration for next lifecycle**	**Use appropriate customer segmentation strategies with respect to self-optimisation**
Customer service focus with respect to goal orientation	(1,1,1)	(1,3,5)	(1,3,5)	(1,3,5)
Output improvement of products or services	(1/5,1/3,1/1)	(1,1,1)	(1,2,4)	(1,1,1)
Product or service reconfiguration for next lifecycle	(1/5,1/3,1/1)	(1/4,1/2,1/1)	(1,1,1)	(1/4,1/2,1/1)
Use appropriate customer segmentation strategies with respect to self-optimisation	(1/5,1/3,1/1)	(1/1,1/1,1/1)	(1,2,4)	(1,1,1)

Table 4. 32: Fuzzy comparison matrix of lower sub-criteria with respect to the "Information exchange capability"

	Use a fractal paradigm in information systems development	**Development of appropriate information technology**	**Information sharing**	**Use a fractal paradigm in information systems development**
Use a fractal paradigm in information systems development	(1,1,1)	(1,2,4)	(1,2,4)	(1,1,1)
Development of appropriate information technology	(1/4,1/2,1/1)	(1,1,1)	(1,1,1)	(1,1,1)
Information sharing	(1/4,1/2,1/1)	(1/1,1/1,1/1)	(1,1,1)	(1,1,1)
Connectivity	(1/1,1/1,1/1)	(1/1,1/1,1/1)	(1/1,1/1,1/1)	(1,1,1)

Table 4. 33: Fuzzy comparison matrix of the lower sub-criteria with respect to the "Time management and logistics cost capability"

	Logistics postponement and speculation	**Inventory cost**	**Low total cost distribution**	**Responsiveness to customer demand fluctuations**
Logistics postponement and speculation	(1,1,1)	(1,1,1)	(1,3,5)	(1,1,1)
Inventory cost	(1/1,1/1,1/1)	(1,1,1)	(1,3,5)	(1/5,1/3,1/1)
Low total cost distribution	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)
Responsiveness to customer demand fluctuations	(1/1,1/1,1/1)	(1,3,5)	(1,3,5)	(1,1,1)

4.3.2. Derivation of priorities (Fuzzy-AHP)

In the first step, in accordance with equation (3.3), the fuzzy synthetic extent values, with respect to the Main Goal, are determined as follows:

$S_{\textit{Supplier}}$= (5, 10, 16) ⊗ (0.0185, 0.0302, 0.0533) = (0.0925, 0.302, 0.8528)

$S_{\textit{Supply hub}}$= (3.4, 4.66, 8) ⊗ (0.0185, 0.0302, 0.0533) = (0.063, 0.14, 0.426)

$S_{\textit{Manufacture}}$ = (5, 11, 17) ⊗ (0.0185, 0.0302, 0.0533) = (0.092, 0.332, 0.906)

$S_{\textit{Distribution centre}}$ = (2.7, 4.33, 8) ⊗ (0.0185, 0.0302, 0.0533) = (0.05, 0.130, 0.426)

$S_{\textit{Retailer}}$= (2.65, 3.166, 5) ⊗ (0.0185, 0.0302, 0.0533) = (0.049, 0.095, 0.266)

Next, according to equation (3.7), degree of possibility of these synthetic values is computed:

$V(S_{Supplier} \geq S_{Supply\ hub}) = 1$, $V(S_{Supplier} \geq S_{Manufacturer}) = 0.962$, $V(S_{Supplier} \geq S_{Distribution\ centre}) = 1$, $V(S_{Supplier} \geq S_{Retailer}) = 1$

$V(S_{Supply\ hub} \geq S_{Supplier}) = 0.673$, $V(S_{Supply\ hub} \geq S_{Manufacturer}) = 0.635$, $V(S_{Supply\ hub} \geq S_{Distribution\ centre}) = 1$, $V(S_{Supply\ hub} \geq S_{Retailer}) = 1$

$V(S_{Manufacturer} \geq S_{Supplier}) = 1$, $V(S_{Manufacturer} \geq S_{Supply\ hub}) = 1$, $V(S_{Manufacturer} \geq S_{Distribution\ centre}) = 1$, $V(S_{Manufacturer} \geq S_{Retailer}) = 1$

$V(S_{Distribution\ centre} \geq S_{Supplier}) = 0.66$, $V(S_{Distribution\ centre} \geq S_{Supply\ hub}) = 0.973$, $V(S_{Distribution\ centre} \geq S_{Manufacturer}) = 0.623$, $V(S_{Distribution\ centre} \geq S_{Retailer}) = 1$

$V(S_{Retailer} \geq S_{Supplier}) = 0.457$, $V(S_{Retailer} \geq S_{Supply\ hub}) = 0.819$, $V(S_{Retailer} \geq S_{Manufacturer}) = 0.423$, $V(S_{Retailer} \geq S_{Distribution\ centre}) = 0.860$

Then, weights of each main criterion are determined using the equation (3.9):

$d'(Supplier) = min\ (1, 0.962, 1, 1)$

$d'(Supply\ hub) = min\ (0.673, 0.635, 1, 1)$

$d'(Manufacturer) = min\ (1, 1, 1, 1)$

$d'(Distribution\ Centre) = min\ (0.66, 0.973, 0.623, 1)$

$d'(Retailer) = min\ (0.457, 0.819, 0.423, 0.860)$

And the weight vector is obtained using the minimum of the degrees of possibility which are found as above (see equation 3.10):

$W' = (0.962, 0.635, 1, 0.623, 0.423)^T$

Finally, the equation (3.11) is used to normalize the priority weights of the main criteria with respect to the Main Goal:

$W_{Main\ Criteria} = (0.264, 0.174, 0.274, 0.171, 0.116\ )^T$

According to the results, *Manufacture* was the most important criteria (0.274), followed by *Supplier* (0.264), *Supply hub* and *Distribution Centre* were close behind (0.174 & 0.171) respectively, and *retailer* was the lowest important main criteria (0.116) with respect to the 'Main Goal'.

The abovementioned steps were applied to the rest of the matrixes which represents the pairwise comparison of sub-criteria and lower sub-criteria and the local priorities were obtained.

Table 4.34 demonstrates the weights of sub-criteria with respect to the relevant main criteria where, with respect to the 'Supplier', *Integration* was most important sub-criteria (0.282) while, with respect to the 'Supply hub, Manufacture, Distribution centre and Retailer' *Supply-oriented capability* (0.306), *Time management and logistics cost capability* (0.408), both *Customer demand-oriented capability* and *Information exchange capability* (0.302) and *Customer demand-oriented capability* (0.281) were most important sub-criteria, respectively.

Table 4. 34: Sub criteria weights with respect to the relevant main criteria

	Supplier	**Supply hub**	**Manufacture**	**Distribution Centre**	**Retailer**
Integration	0.282	0.261	0.141	0.084	0.216
Supply-oriented capability	0.180	0.306	0.044	0.156	0.269
Customer demand-oriented capability	0.240	0.210	0.219	0.156	0.281
Information exchange capability	0.181	0.048	0.188	0.302	0.074
Time management and logistics cost capability	0.117	0.175	0.408	0.302	0.160

As given in Figure 4.20, *Fractal information system integration* was the most importance lower sub-criteria (29%) followed by *Standardization and simplification, with respect to self-similarity and self-organisation* (24%), *Cross-functional unification, with respect to self-similarity* (18%), *Compliance, with respect to goal orientation* (17%), and *Structural adaptation, with respect to self-organisation and dynamics*, was ranked of lowest importance in the lower sub-criteria (12%) with respect to the 'Integration'.

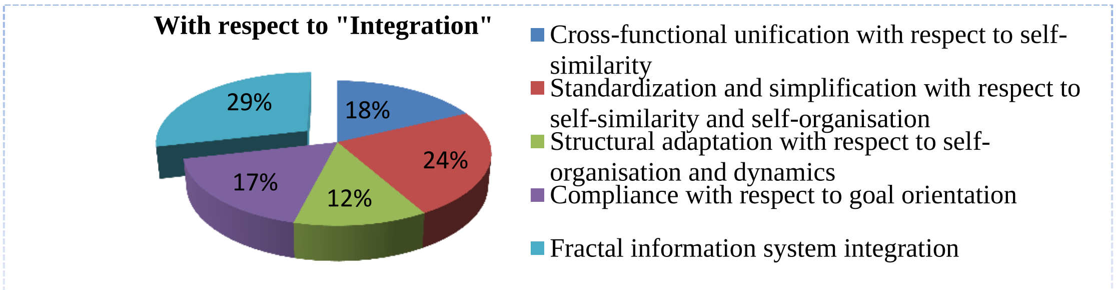


Figure 4. 20: lower sub criteria prioritization with respect to the "Integration"

Figure 4.21 illustrates that, with respect to the 'Supply-oriented capability', *Supplier selection, relationship and involvement in the fractal supply network* was the most important lower sub-criteria (37%) followed by *Selective distribution coverage, with respect to goal orientation* (33%), and both *Reverse logistics in the fractal supply network* and *Operating across different businesses and different regions* with the least ranking (15%).

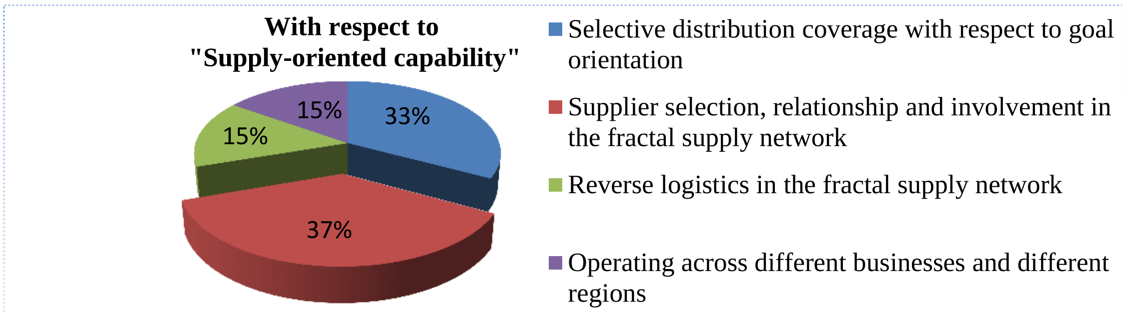


Figure 4. 21: Lower sub criteria prioritization, with respect to the "Supply-oriented capability

Figure 4.22 demonstrates that, with respect to ‘Customer demand-oriented capability’, *Customer service focus with respect to goal orientation* was the most importance of the lower sub-criteria (38%) followed by *Output improvement of products or services* and *Use of appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation* (24%) and *Product or service reconfiguration for the next lifecycle* with the lowest ranking (14%).

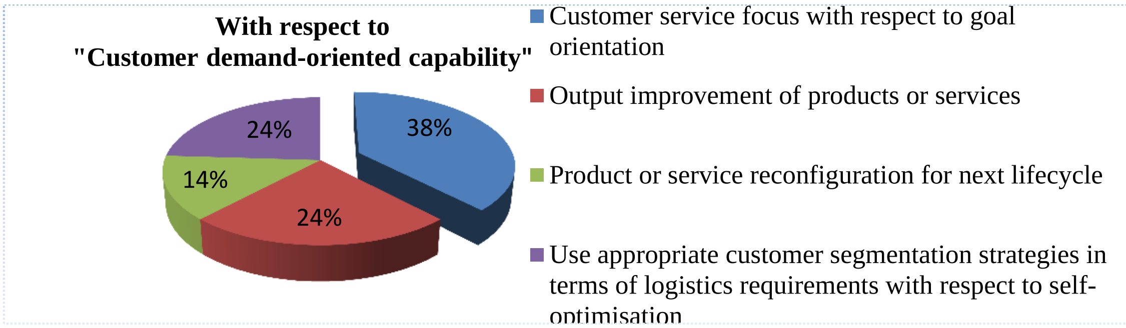


Figure 4. 22: Lowest sub criteria prioritization with respect to the ‘Customer demand-oriented capability’

With respect to the ‘Information exchange capability’, *Use a fractal paradigm in information systems development* was the most important of the lower sub-criteria (44%) followed by *Connectivity* (20%) and both *Development of appropriate information technology* and *Information sharing* the lowing ranking (18%) (see Figure 4.23).

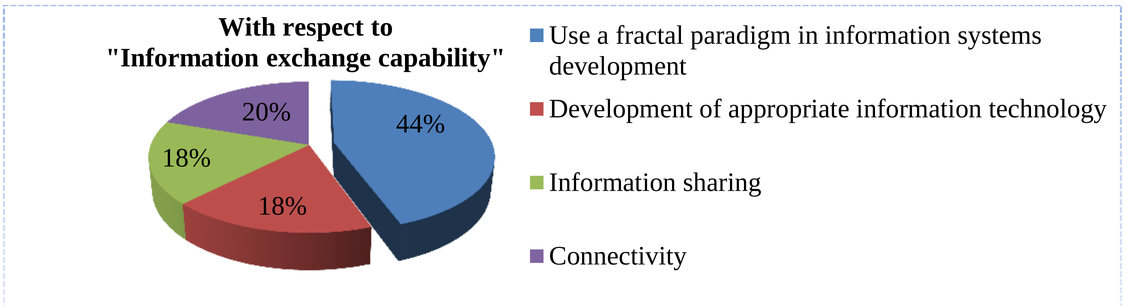


Figure 4. 23: Lower sub criteria prioritization with respect to the ‘Information exchange capability’

As given in Figure 4.24, with respect to the 'Time management and logistics cost capability', *Responsiveness to customer demand fluctuations* was the most important of the lower sub-criteria (0.33%) followed by both *Logistics postponement and speculation* and *Inventory cost* (0.27%), and *Low total cost distribution achieved* the lowest ranking (13%).

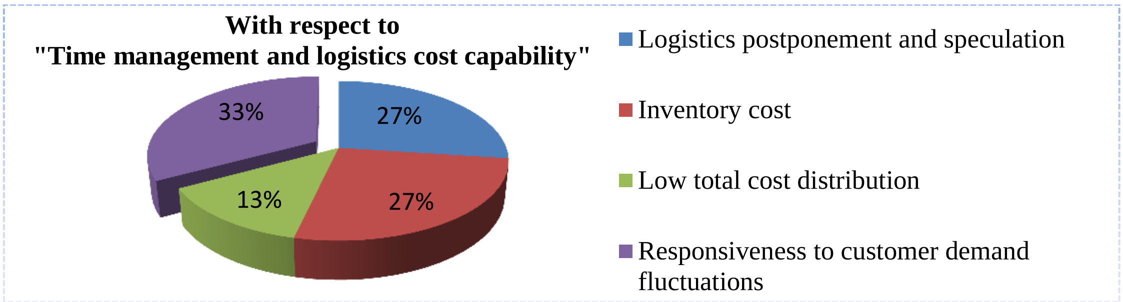


Figure 4. 24: Lower sub criteria prioritization with respect to the 'Time management and logistics cost capability'

4.3.3. Synthesizing the results (Fuzzy AHP)

After deriving the local priorities for the criteria, sub-criteria and lower sub criteria through pairwise comparisons, the synthesis analysis has been done to understand the global priorities of the lower sub criteria towards the main goal and each main criterion using equation (4.5) and (4.6).

As given in figure 4.25, *Customer service focus, with respect to goal orientation,* received the highest ranking (8.3%), followed by *Responsiveness to customer demand fluctuations* (8%), *Use of a fractal paradigm in information systems development* (7.6%) and *Structural adaptation, with respect to self-organisation and dynamics*, was the lowest ranked (2.4%) with respect to the 'main goal'.

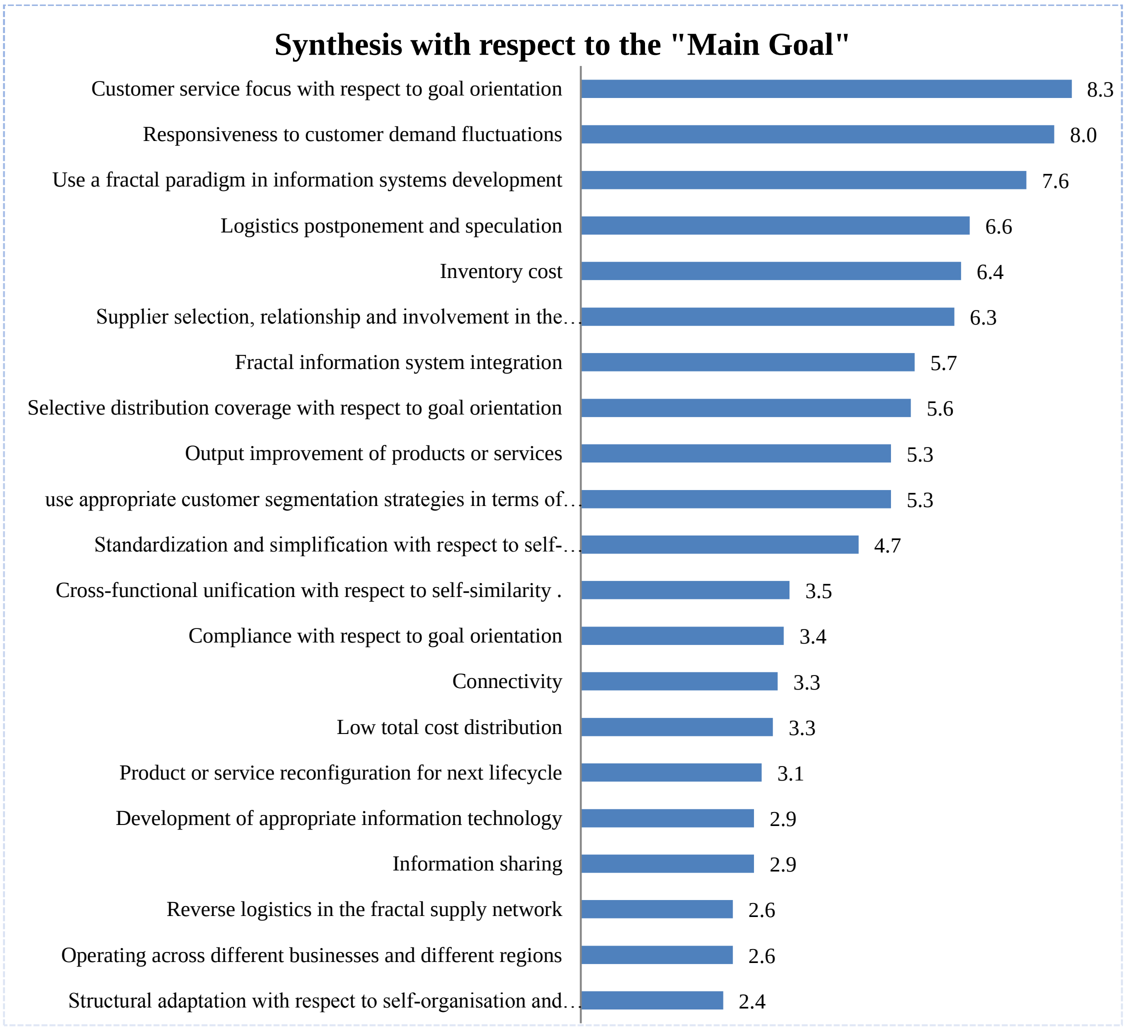


Figure 4. 25: Global priorities of all lower sub-criteria with respect to the "Main Goal" (Fuzzy AHP) (%)

Figure 4.26 illustrates that, with respect to the 'Supplier', *Customer service focus, with respect to goal orientation*, was the most important of the lower sub-criteria (9.1%), followed by both *Fractal information system integration* and *the use of a fractal paradigm in information systems development* (8.1%), and *Low total cost distribution* (1.6%) achieved the lowest ranking.

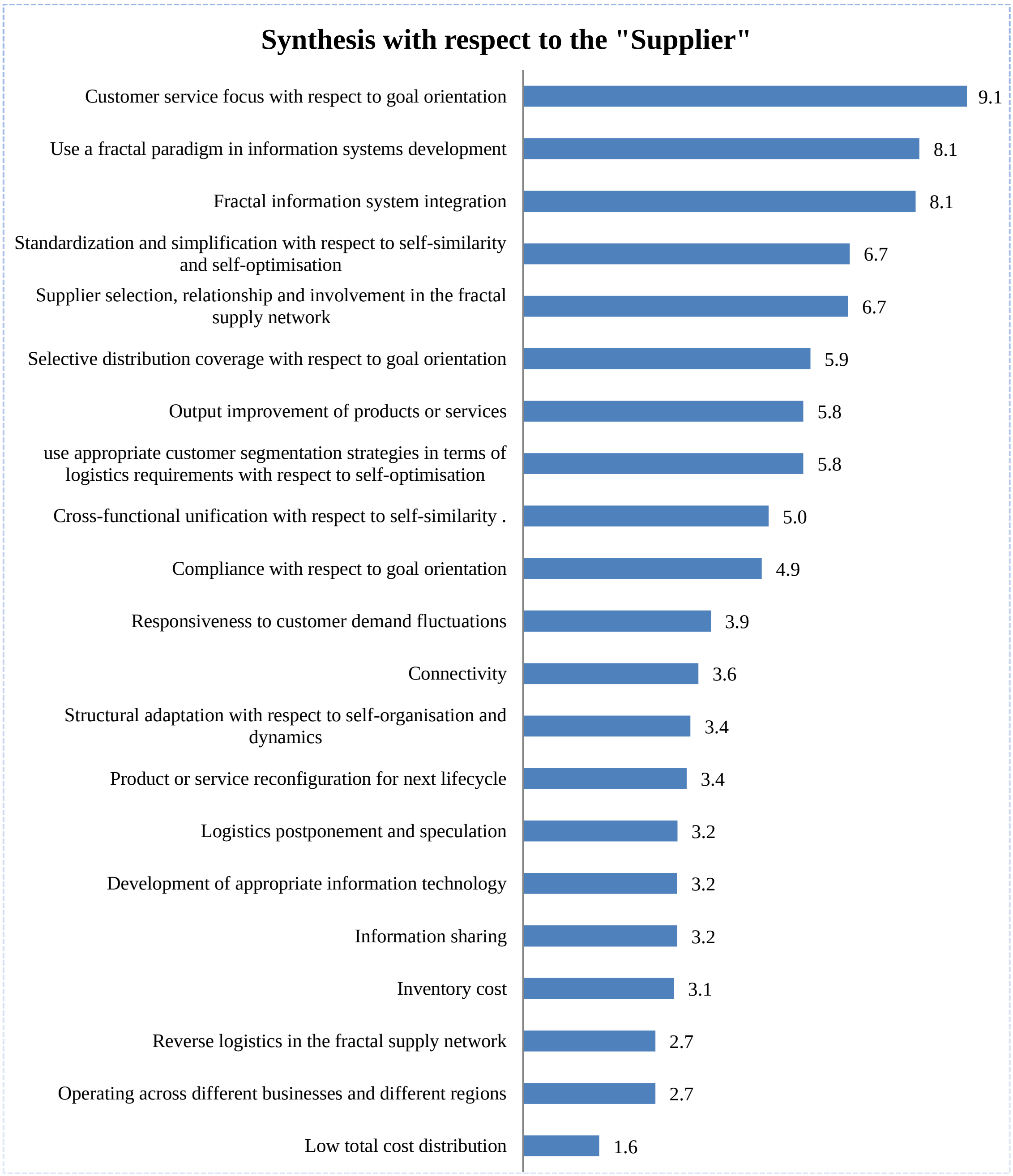


Figure 4. 26: Global priorities of all lower sub-criteria with respect to the 'Supplier' (Fuzzy AHP) (%)

Figure 4.27 demonstrates that, with respect to the 'Supply hub', *Supplier selection, relationship and involvement in the fractal supply network* was the most important of the lower sub-criteria (11.4%), followed by *Selective distribution coverage, with respect to goal orientation* (10%), *Customer service focus, with respect to goal orientation* (8%) and both *Development of appropriate information technology* and *Information sharing* (0.8%) were the lowest ranked.

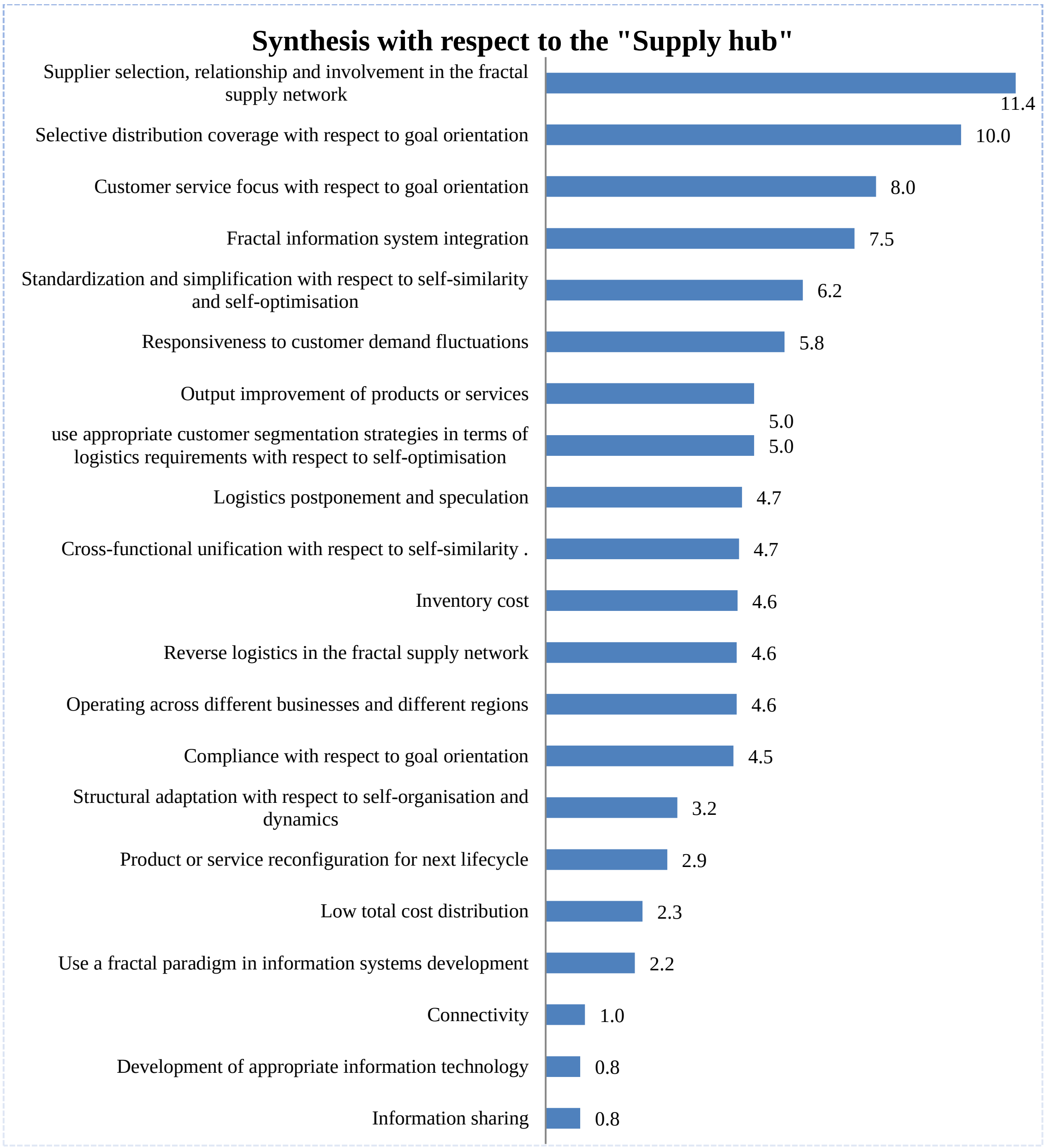


Figure 4. 27: Global priorities of all lower sub criteria with respect to the "Supply hub" (Fuzzy AHP) (%)

Figure 4.28 shows that, with respect to the 'Manufacturer', *Responsiveness to customer demand fluctuations* was the most important lower sub-criteria (13.5%), followed by *Logistics postponement and speculation* (11.1 %), *Inventory cost* (10.8%) and both *Reverse logistics in the fractal supply network* and *Operating across different businesses and different regions* were the lowest ranked (0.7 %).

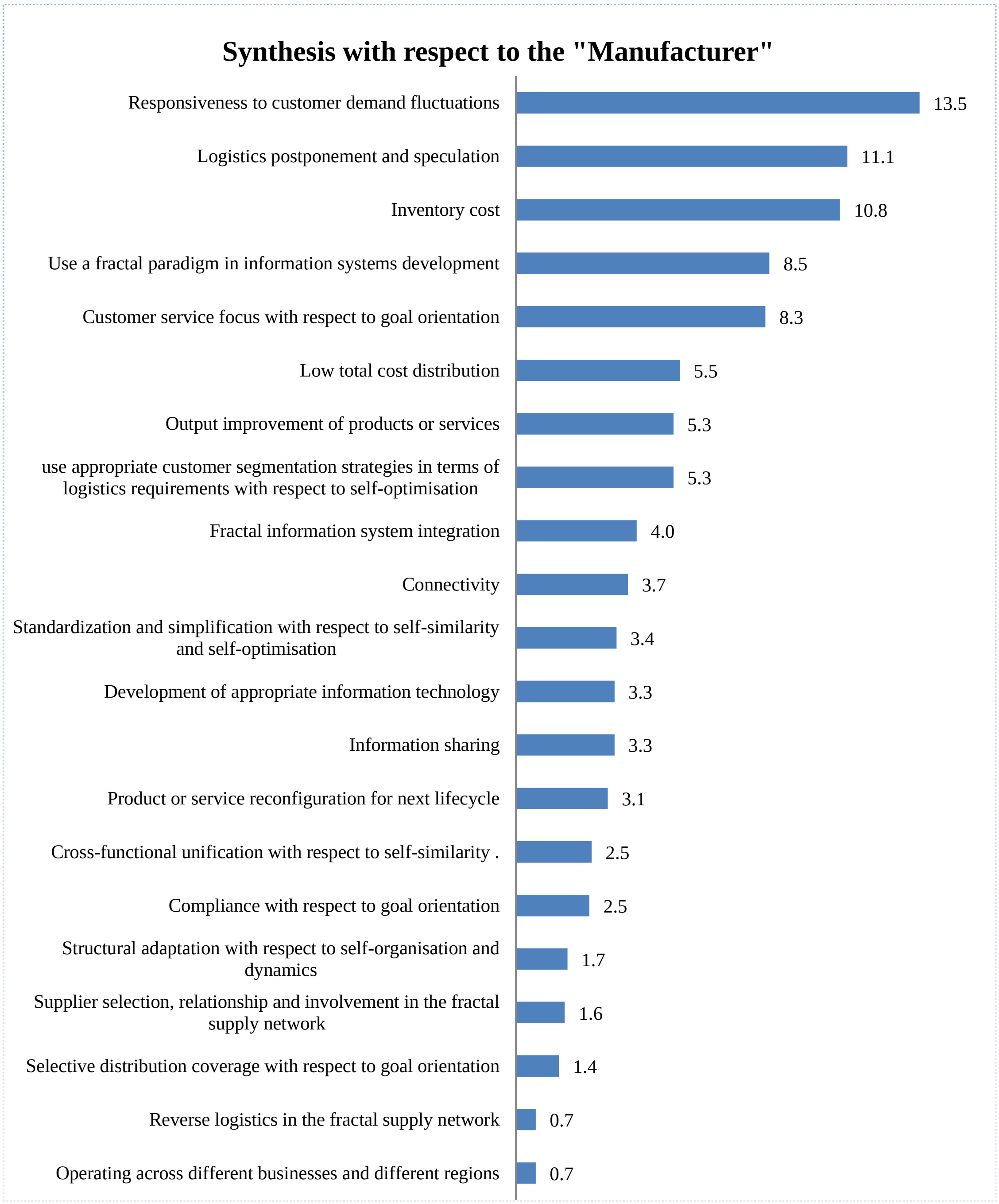


Figure 4. 28: Global priorities of all lower sub-criteria with respect to the "Manufacturer" (Fuzzy AHP) (%)

Figure 4.29 indicates that, with respect to the 'Distribution centre', *The use a fractal paradigm in information systems development* was the most important of the lower sub-criteria (13.6%), followed by *Responsiveness to customer demand fluctuations* (10 %), *Logistics postponement and speculation* (8.2%) and *Structural adaptation with respect to self-organisation* (1.0%) achieved the lowest ranking

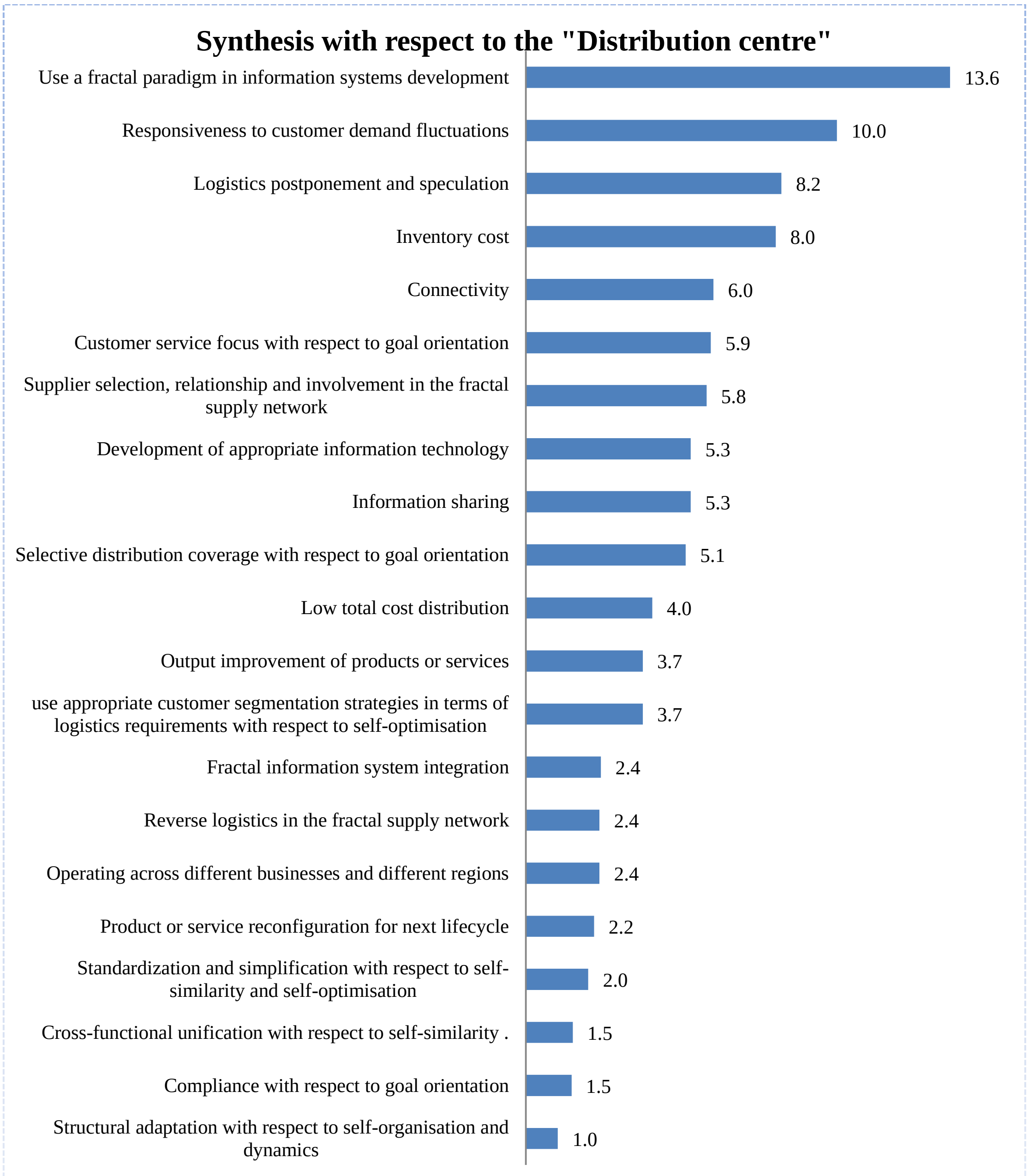


Figure 4. 29: Global priorities of all lower sub-criteria, with respect to the 'Distribution Centre' (Fuzzy AHP) (%)

Figure 4.30 shows that, with respect to the 'Retailer', the *Customer service focus, with respect to goal orientation*, was the most important lower sub-criteria (10.7%), followed by *Supplier selection, relationship and involvement in the fractal supply network* (10%), *Selective distribution coverage, with respect to goal orientation* (8.8%), and both *Development of appropriate information technology* and *Information sharing* (1.3%) were the lowest ranked.

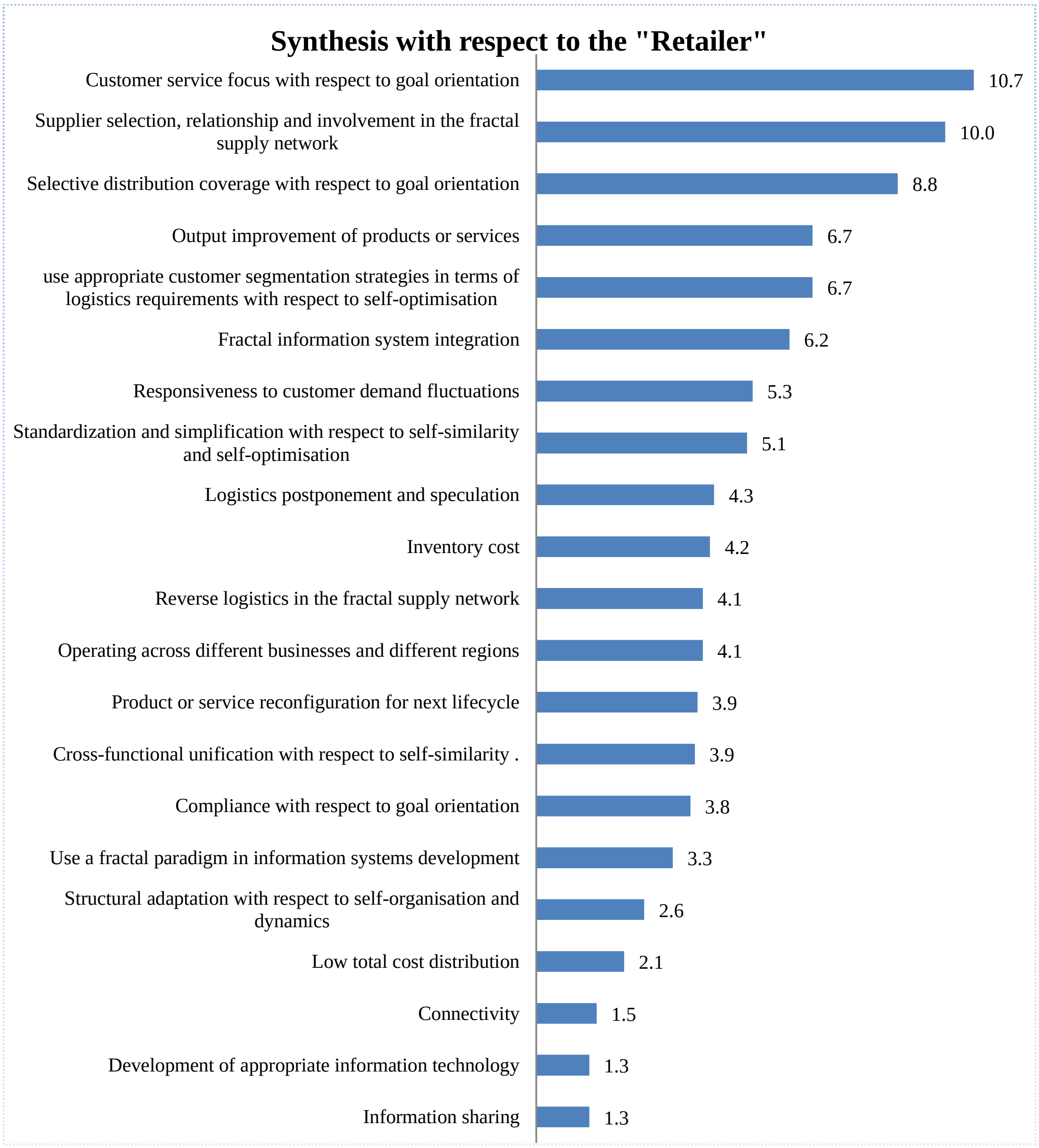


Figure 4. 30: Global priorities of all lower sub-criteria, with respect to the 'Retailer' (Fuzzy AHP) (%)

4.4. Comparison between classical AHP and Fuzzy AHP results

Table 4.35 shows the comparison between local weights derived within each methodology. There is a slight difference between classical AHP prioritisation ratio and Fuzzy AHP ratio. As Fuzzy AHP considers a set of values (TFN) rather than a single value, the prioritisation will be more certain. It is noticeable that, as shown in figures 4.14 and 4.25, the global Fuzzy AHP weights, with respect to the main goal, also shows that there is a slight difference in the importance of elements in each criterion with respect to the classical AHP.

Table 4. 35: Comparison between classical AHP and Fuzzy AHP results (%)

Main criteria	Sub-criteria	Fuzzy-AHP	Classical AHP
Supplier	Integration capability	28.2	37.9
	Supply-oriented capability	18	14.2
	Customer demand-oriented capability	24	22
	Information exchange capability	18.1	15.4
	Time management and logistics cost capability	11.7	10.6
Supply hub	Integration capability	26.1	25.5
	Supply-oriented capability	30.6	42.3
	Customer demand-oriented capability	21	14.4
	Information exchange capability	4.8	5.5
	Time management and logistics cost capability	17.5	12.3
Manufacturer	Integration capability	14.1	12
	Supply-oriented capability	4.4	5.2
	Customer demand-oriented capability	21.9	17.4
	Information exchange capability	18.8	14.8
	Time management and logistics cost capability	40.8	50.6
Distribution centre	Integration capability	8.4	7.1
	Supply-oriented capability	15.6	11.8
	Customer demand-oriented capability	15.6	11.8
	Information exchange capability	30.2	34.6
	Time management and logistics cost capability	30.2	34.6
Retailer	Integration capability	21.6	16
	Supply-oriented capability	26.9	29
	Customer demand-oriented capability	28.1	39.3
	Information exchange capability	7.4	6.2
	Time management and logistics cost capability	16	9.5

4.5. Sensitivity Analysis

In this work, the dynamic sensitivity of Expert Choice was applied to dynamically change the priorities of the main criteria to determine how these changes affect the priorities of the lower sub-criteria. Therefore, the impact of changing the priority of five main criteria 'Supplier, Supply Hub, Manufacturer, Distribution centre and Retailer' on overall results has been investigated (see Figures 4.31-4.35).

As shown in Figure 4.31, in the first scenario when the priority of "Supplier" was dropped to the fourth priority (from 31.2% to 15.2%) the highest and the lowest priority of the final ranking of the lower sub-criteria were preserved whilst the *Logistics postponement and speculation* and *Inventory cost* were raised to the fourth and fifth priority of the final ranking with 8.8% and 6.9% respectively.

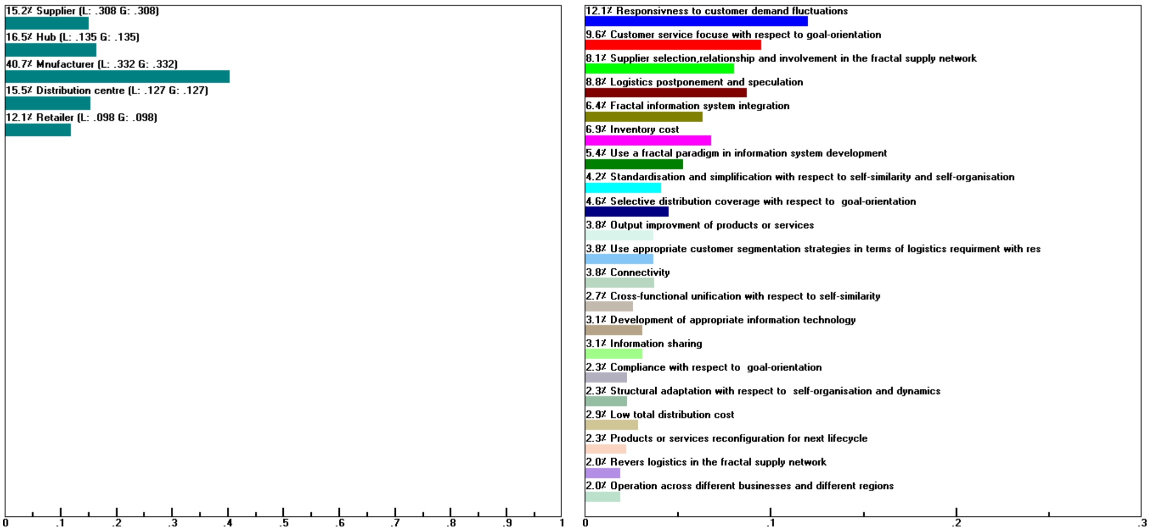


Figure 4. 31: First scenario of Sensitivity analysis

Figure 4.32 illustrates the second scenario when the priority of 'Supply hub' was increased to the highest priority (from 13% to 25%) *Supplier selection, relationship and involvement in the fractal supply network* was raised to the most important lower sub-criteria with 10.3% and *Products or services reconfiguration for next lifecycle* was ranked the lowest with respect to the 'main goal'.

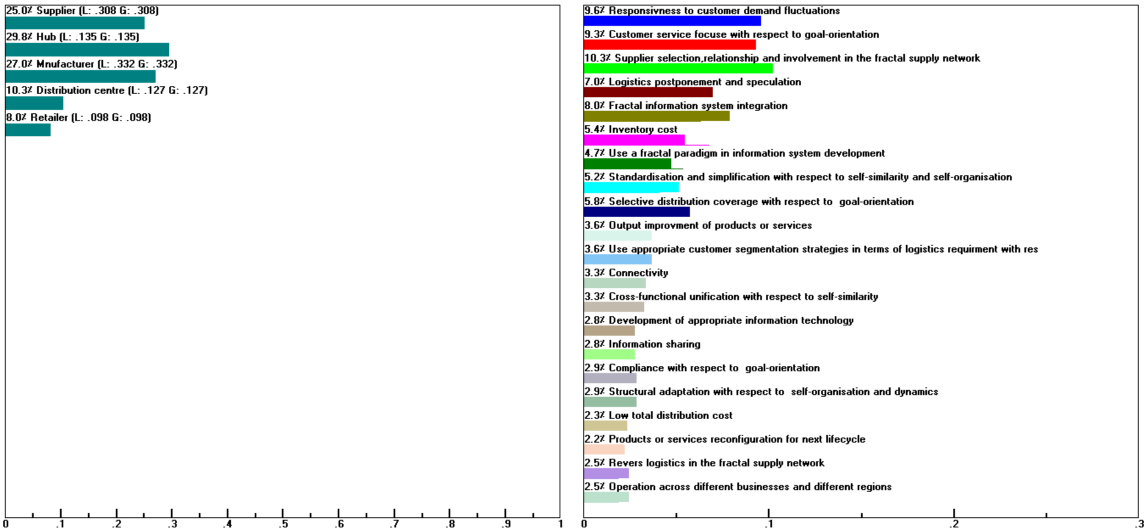


Figure 4. 32: Second scenario of Sensitivity analysis

In the third scenario, when the priority of 'Manufacturer' was dropped to the lowest priority (from 33.8% to 12.3%) *Customer service focus, with respect to goal orientation*, was raised to the highest ranking with 10.2%, followed by *Supplier selection, relationship and involvement in the fractal supply network* with 9.6%, *Fractal information system integration* with 8.8 % and *Low total distribution cost* was the lowest ranking with 1.9% (see Figure 4.33).

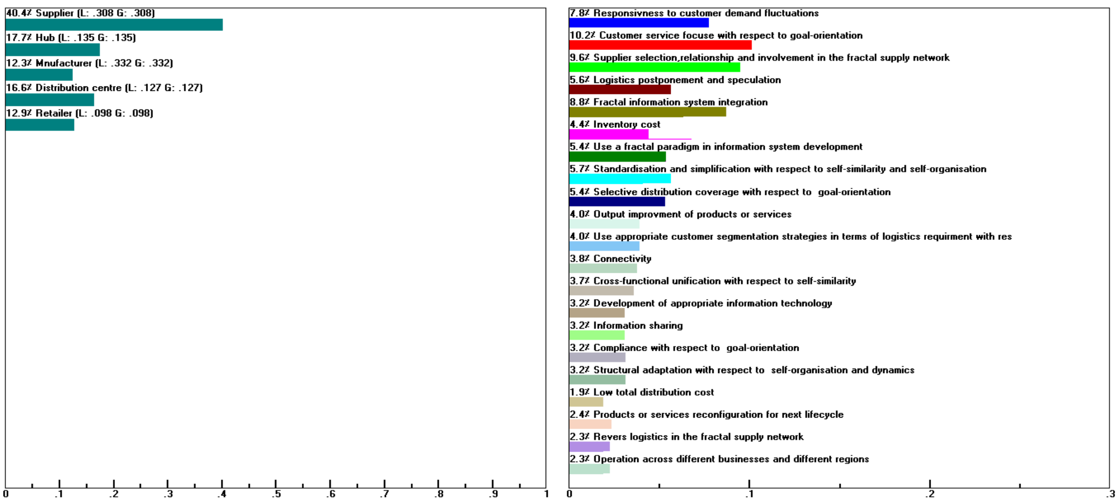


Figure 4. 33: Third scenario of Sensitivity analysis

Figure 4.34 shows the fourth scenario when the priority of ‘Distribution Centre’ was raised to the highest priority (from 12.2% to 28.5%). The highest and the lowest priority of the final ranking of lower sub-criteria were preserved while the *Logistics postponement and speculation* received the third priority with 8.1% instead of *Supplier selection, relationship and involvement in the fractal supply network.*

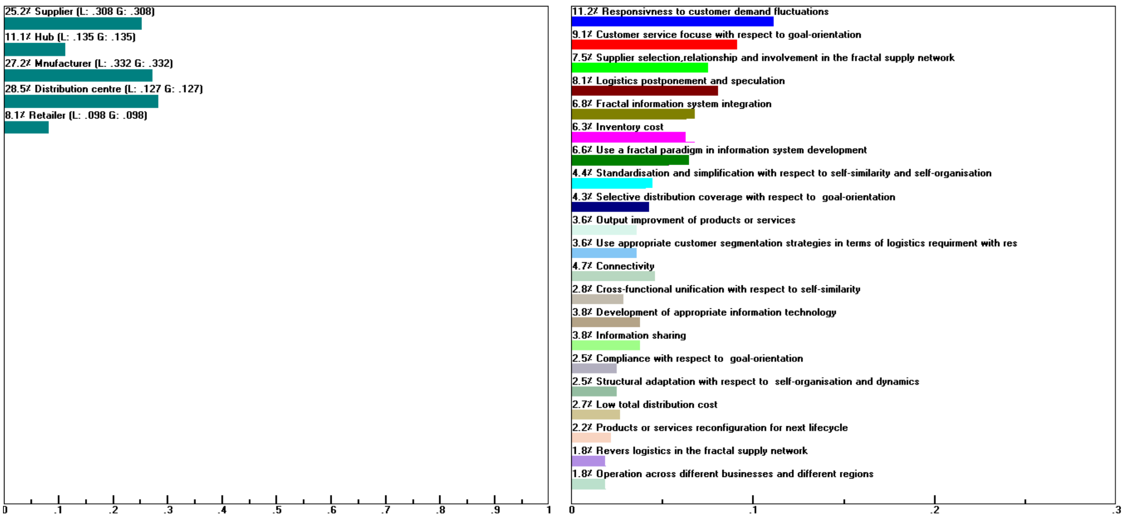


Figure 4. 34: Fourth scenario of Sensitivity analysis

As given in Figure 4.35, in the fifth scenario, when ‘Retailer’ received the highest priority (from 10.4% to 27.8%), *Customer service focus with respect to goal orientation* was raised to the highest priority with 11.7% instead of *Responsiveness to customer demand fluctuations* and both *Reverse logistics in the fractal supply network* and *Operating across different businesses and different regions* with 2.2% were still the lowest ranked.

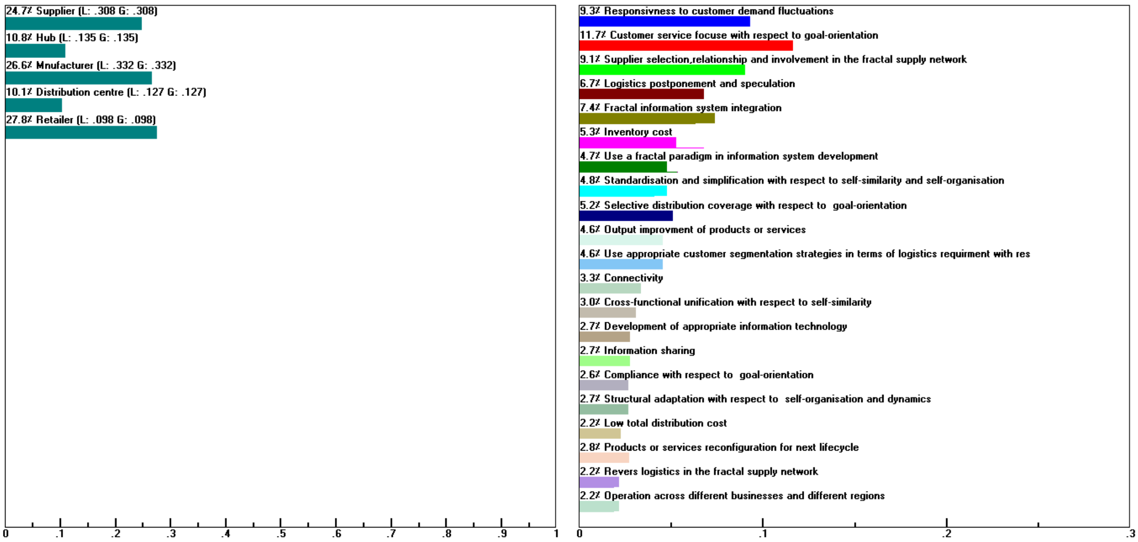


Figure 4. 35: Fifth scenario of Sensitivity analysis

4.6. Conclusions

Measuring logistics capability is one of the challenging issues in today's competitive business scenario. An efficient and effective measurement can lead to improvement in the process and, thus, competitiveness can be achieved. Unlike previous research, this paper considered the logistics capabilities from the perspective of a fractal supply network and the majority of logistics categories which are rarely carried out within previous literature.

In this study, the criteria for measuring logistics capabilities in the fractal supply network have been decided based on the previous literature, fractal capabilities and expert's judgements in this field. Considering the imprecise judgement faced by decision makers from classical AHP methodology, a fuzzy AHP methodology has also been used in this study to attain a clearer, more precise, priority from each level of judgement for measurement depending on their criticality. Moreover, a sensitivity analysis has been applied in this work to understand how the changes in priority of one criterion affect another.

To answer the first research question of this study, in which "*To what extent the priorities concerning logistics capabilities among fractal supply network members are the same*?" the result revealed that *Integration capability* was the most important capability with respect to "Supplier". However, with respect to "Supply hub, Manufacturer, Distribution Centre and Retailer" *Supply-oriented capability*, *Time management and logistics cost capability*, both *Information exchange capability* and *Time management and logistics cost capability* and *Customer demand-oriented capability* were the most important capabilities respectively.

From a practical point of view, it is apparent that this work provides a systematic method through which practitioners should be able to decide upon the different logistics capabilities factors, sub-factors and key elements to test, assess and improve the enterprise's logistics capabilities.

Chapter Five – The development of a dynamic information fractal framework to monitor and optimise sustainability in the distribution network

The aim of this chapter is to develop a new framework for an information fractal to improve distribution network sustainability through two variables; Greenfield service constraints and minimum vehicle weight fill level on board.

The proposed framework consists of two levels; top and bottom level fractals. Dynamically, top-level fractal investigates the sustainability status of a distribution network and transmits decisions concerning network reconfiguration for further improvement to the bottom level fractals. Fractals at the bottom level implement the reconfiguration orders and apply green vehicle route optimisation and then transmit sustainability performance information to the top-level fractal.

Supply Chain GURU Software was adapted to implement Greenfield analysis to identify the optimal number and location for setting up the new facilities through different Greenfield service constraints. A new Green Split Delivery-Vehicle Route Problem (GSD-VRP) is developed to minimise CO_2 emission and implemented using simulated annealing algorithm which is programmed in MATLAB software.

5.1. The proposed framework for Information Fractal Distribution Network (IFDN)

Figure 5.1 displays the new proposed framework of an IFDN through a distribution network with two levels including an *Information Fractal – Reconfiguration Centre* as a top-level fractal and the *Information Fractal- Distribution Centres* as a bottom-level fractal with their own assigned retailers.

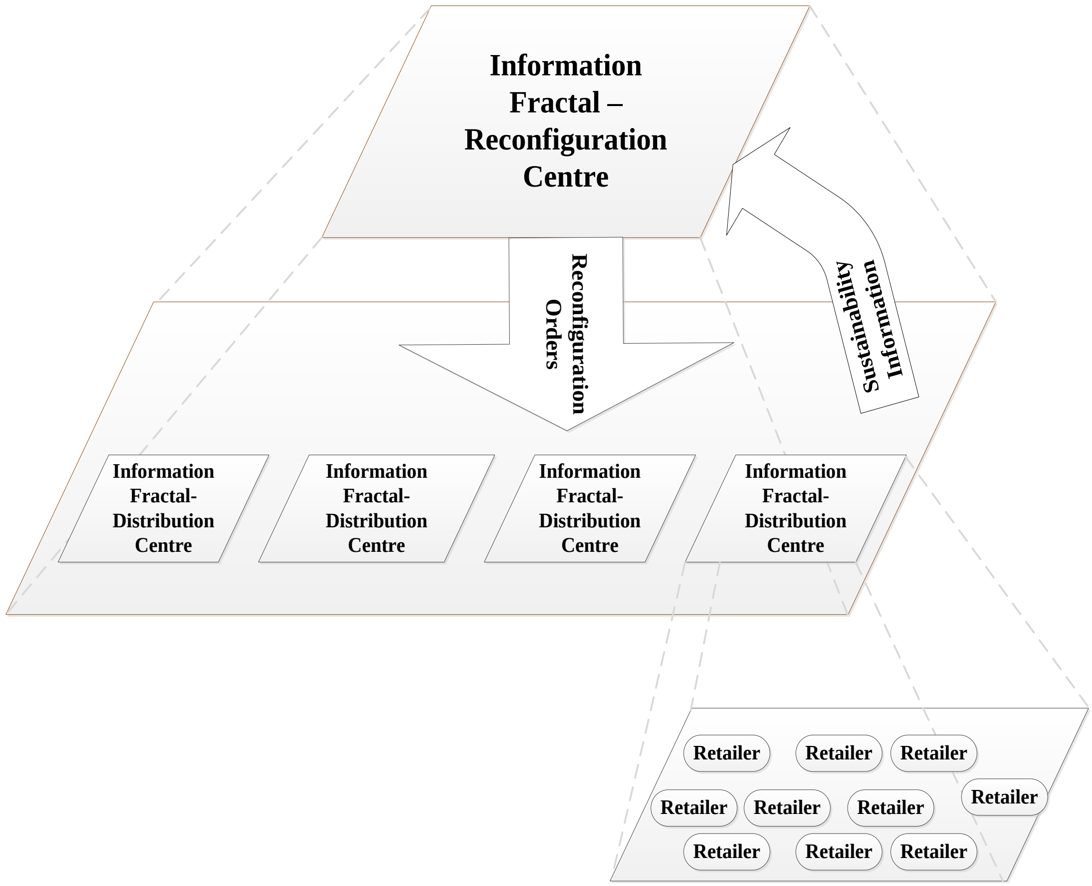


Figure 5. 1: The proposed framework for an Information Fractal Distribution Network (IFDN)

According to Ryu et al. (2013), each information fractal unit consists of five function models including observer, analyser, resolver, organiser and reporter as a basic fractal unit (BFU), see Figure 5.2.

In the bottom level fractal, observers in the distribution centres trace and receive the reconfiguration orders from reconfiguration centre, transmit the orders to analysers and notify resolvers to receive the new restructuring orders. Resolvers transmit the orders to organisers to apply the reconfiguration. Once the fractal reconfiguration is done, resolvers apply green vehicle route optimisation through their assigned retailers. Analysers use output data which is transmitted from resolvers to investigate sustainability performance measures and return analysis results. Then, resolvers transmit the fractal sustainability information to the reconfiguration centre through the reporter function.

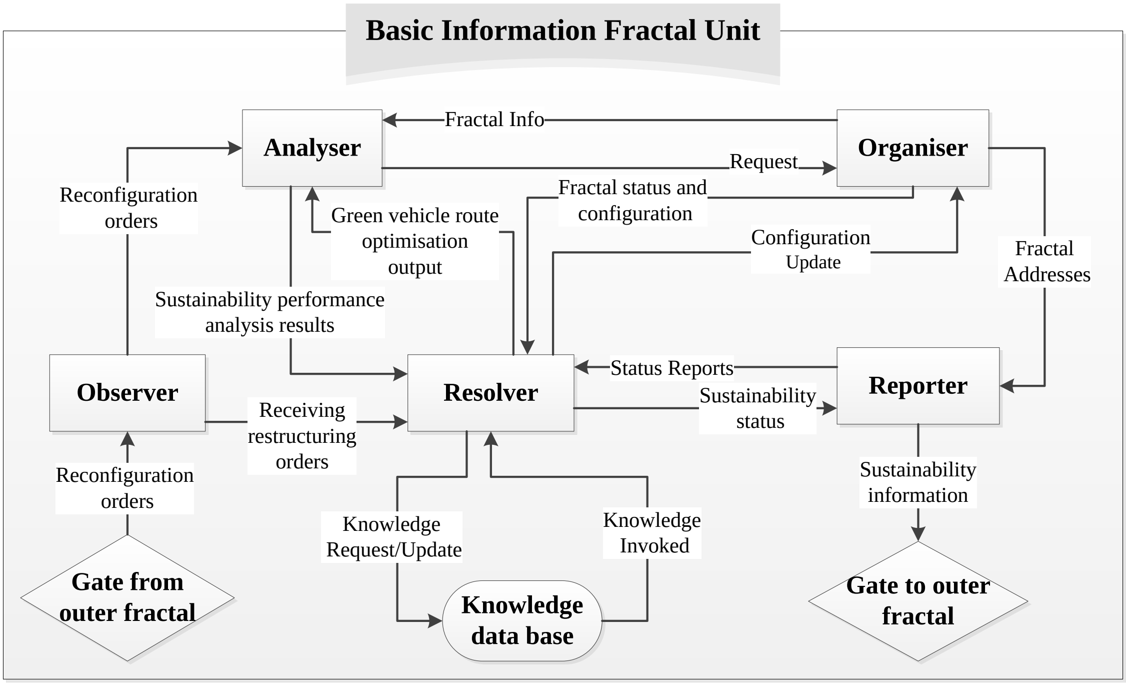


Figure 5. 2: Basic Information Fractal Unit Structure for the bottom-level fractal

In the top-level fractal, the observer traces and receives reconfiguration outputs from the bottom level shown as ‘Gate from outer fractal’ (see Figure 5.2), then transmits them to the analyser and notifies the resolver. The analyser investigates and analyses the distribution network sustainability status and transmits the analysis results to the resolver. The resolver may make decisions for any further improvement and network restructuring regarding the analyser's investigation. If the reconfiguration is specified by the resolver, the order should be sent to the organiser to apply the network reconfiguration. Then, the organiser notifies the resolver of which order is performed. Finally, resolvers transmit the reconfiguration orders to each distribution centres located in the bottom level through reporter function which is shown as ‘Gate to outer fractal’ (see Figure 5.3).

This structure is demonstrated in Figure 5.3 and clearly explains the internal relationships between these five function models.

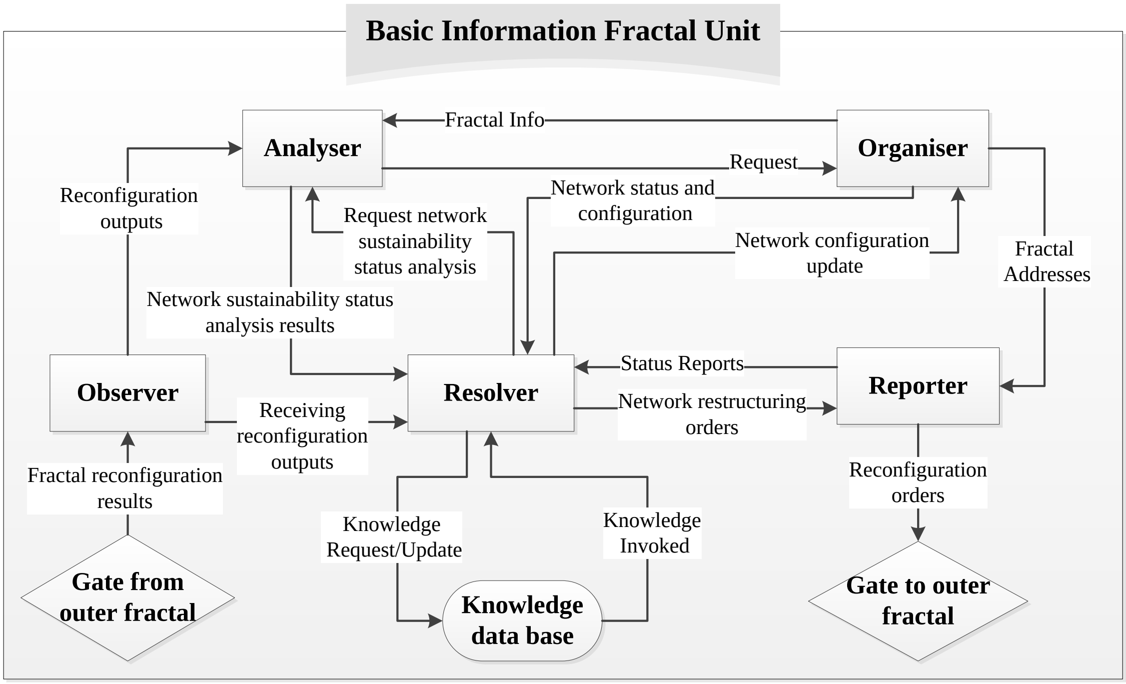


Figure 5. 3: Basic Information Fractal Unit Structure for the top-level fractal

As part of the top-level's information fractal performance, Supply Chain GURU Software was adapted to implement Greenfield analysis to identify the optimal number and location for setting up the new facilities, given the location and demand of customers with different service constraints aiming to improve distribution network sustainability.

In this method, the objective is to minimise the total weighted distance. The Greenfield service constraints enable a specification of the percentages of customers or demand to be served within specified distances from the Greenfield site, which has a significant relationship with transportation costs, CO_2 emissions, transportation time and the number of vehicles in the required fleet (Saad & Bahadori, 2017).

As part of the information fractal performances, which are in the bottom level, an integer mathematical model is proposed and presented in the next section with which the simulating annealing algorithm is used as a heuristic technique to identify the optimum/near-optimum solution.

5.2. Green vehicle route optimisation mathematical model

In this research, a Pollution-Routing Problem (PRP) with a homogeneous fleet of vehicles is employed and the possibility of split delivery considered as is the constraint of minimum shipment weight that must be on the vehicle during its service in each route which is investigated simultaneously. Its integer linear programming model of the problem is described as follows:

5.2.1. Input parameters

V: Total number of nodes; with vertex set $V = \{0, 1, \dots, n\}$; Where node 0 corresponds to the depot and the other nodes in this set of vertex represent the customers.

A: sets of edges; $A = \{(i,j) \mid i, j\} \in V$ and $i \neq j\}$.

K: Number of available vehicles; $K = \{1, ..., k\}$ and the number of vehicles is unlimited.

Q_k= Capacity of k^{th} vehicle ($k \in K$).

D_i= Customers demand ($i \in V$).

d_{ij} = Length of edge between the nodes i and j $(i,j) \in A$

M_{sk} = Minimum shipment weight that must be on the k^{th} vehicle for the length of each route during its service

C_{ijk}= CO_2 emission of moving k^{th} vehicle ($k \in K$) between the nodes i and j

Where:

$C_{ijk} = \left(\left(T_{wk} + W_{ijk}\right) \times R_{ck}\right) \times d_{ij}$

And

T_{wk} =Tare weight of k^{th} vehicle, which is the weight of the empty vehicle.

W_{ijk}= Weight of shipments on board of k^{th} vehicle between the nodes i and j

R_{ck}= CO_2 emission rate of k^{th} vehicle

5.2.2. Decision variables

$$x_{ijk} = \begin{cases} 1 & \text{if } j^{th} \text{ customer is served by } k^{th} vehicle \text{ after } i^{th} \text{ customer} \\ 0 & otherwise \end{cases}$$

y_{ik}= the quantity of the demand of i^{th} customer which is delivered by the k^{th} vehicle.

5.2.3. Formulation

Therefore, the vehicle route problem formulation by Dror & Trudeau (1990) can be modified in order to consider the CO_2 emission and guarantee minimum vehicle weight fill level on board in order to formulate the proposed Green Vehicle optimisation model in this study as follows:

$$\sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{K} C_{ijk}x_{ijk} \ , \qquad i \neq j \tag{5.1}$$

Subject to

$$\sum_{i=0}^{n}\sum_{k=1}^{K} x_{ijk} \geq 1, \qquad\qquad j = 1, \dots, n, \tag{5.2}$$

$$\sum_{i=0}^{n} x_{ipk} - \sum_{j=0}^{n} x_{pjk} = 0\,, \qquad p = 0,\ldots,n;\ k = 1,\ldots,K, \tag{5.3}$$

$$\sum_{i=1}^{n} W_{ijk} \geq M_{sk}\,, \qquad j = 2,\ldots,n; \quad k = 1,\ldots,K \tag{5.4}$$

$$y_{ik} \leq D_i \sum_{j=0}^{n} x_{ijk}\,, \qquad i = 1,\ldots,n;\ k = 1,\ldots,K \tag{5.5}$$

$$\sum_{k=1}^{K} y_{ik} = D_i, \qquad i = 1,\ldots,n \tag{5.6}$$

$$\sum_{i=1}^{n} y_{ik} \leq Q, \qquad k = 1,\ldots,K \tag{5.7}$$

$$\sum\nolimits_{i,j\in S} x_{ijk} \leq |S| - 1, \qquad (S \subset \{1,\ldots,n\});\ |S| \geq 2 \tag{5.8}$$

$$x_{ijk} \in \{0,1\}, \qquad i = 0,\ldots,n\,;\ j = 0,\ldots,n; k = 1,\ldots,K \tag{5.9}$$

$$y_{ik} \geq 0, \qquad i = 1,\ldots,n;\ k = 1,\ldots,K \tag{5.10}$$

The objective function represents the minimisation of the total CO_2 emission produced by usage of the transportation fleet. Constraints (5.2) ensure that each customer is visited at least once. Constraints (5.3) mean that any vehicle that enters each node will definitely leave it. Constraints (5.4) guarantee that vehicle cannot continue to serve more customers along the each route if the weight of its shipment on board coming down from specified minimum shipment weight. Constraints (5.5) ensure that the i^{th} customer's demand is completed if at least one vehicle passes through it. Constraints (5.6) indicate that all customers demand is entirely fulfilled, while constraints (5.7) impose that the loading process on any route should not exceed the capacity of the vehicle. Constraints (5.8) present the sub tour elimination constraints.

The vehicle route optimisations model, which is presented above, is applied by resolvers; to minimise the CO_2 emission. Moreover, analysers also start to measure other sustainability factors that affect performance including transportation costs, transportation time and the number of required vehicles which are needed to meet customers' demands. For these purposes, the following equations are developed.

5.2.4. Total transportation cost

$$T_C = \sum_{i=0}^{n} \sum_{j=1}^{n} \sum_{k=1}^{k} d_{ijk} \times A_C \tag{5.11}$$

Where

T_C= Total transportation cost

A_C = Average transportation cost per km

d_{ijk}= The length of an edge between nodes i and j travelled by vehicle k.

5.2.5. Total transportation time

$$T_t = \sum_{i=0}^{n} \sum_{j=1}^{n} \sum_{k=1}^{k} \frac{d_{ijk}}{F_{vk}} \tag{5.12}$$

Where

T_t = Total transportation time route

F_{vk} = Fleet velocity (km/h) of vehicle k

5.2.6. Total number of required vehicles

The proposed mathematical model allocates certain numbers of customers to be served according to its max load capacity until all customers' demand has been fulfilled. This will lead to the Total Number of Vehicles required (TNV) to be identified as an output from the proposed model.

5.3. Application of the proposed framework for an Information Fractal Distribution Network

In this research, a hypothetical distribution network and its data is considered: A large British food and beverage company wanted to determine the best number and location for distribution centres (DC) facilities as well as optimal number of required fleet to meet customers demand for its national operations with multi-objective approach; minimisation of CO_2 emissions, transportation costs and maximise responsiveness. The company serves 340 stores around the country, the customers' daily demand weights (kg) are randomly selected from *n* (1000, 4000). Figure 5.4 displays the GURU snapshot of the store's distribution.

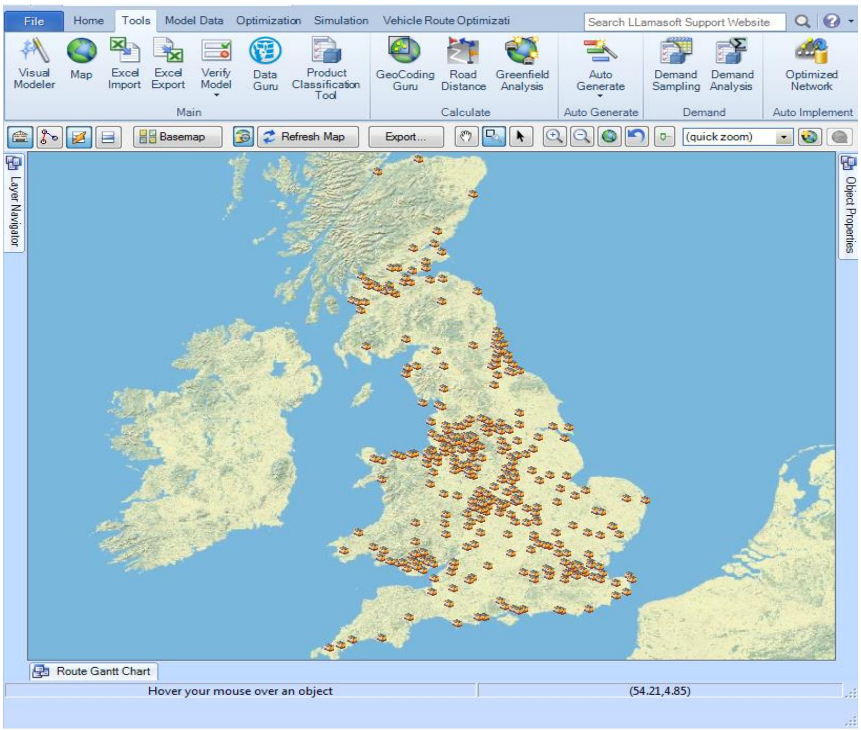


Figure 5. 4: Supply Chain Guru Screen Shot of the Considered Retailers

There is homogeneous fleet available at the company (rigid 7.5 ton). The capacity of the vehicle is determined as 3000 kilograms with a CO_2 emission rate of 0.0005442 kg per km (DEFRA, 2010). Moreover, average transportation costs, average vehicle's velocities and vehicle's tare weight are considered to be £2.1 per km, 90 km/h (56 mph) and 3000 kg respectively. In addition, there are some other assumptions listed below and obviously we should review the obtained results within the domain of these assumptions, which may represents some limitations hat can be considered as part of future work.

5.4. Result analysis and discussion

5.4.1 Greenfield analysis results

As part of dynamic reconfiguration, to achieve the company's sustainability objectives, three reconfiguration scenarios are approved by the resolver in top-level fractal in which 100% of customers are served within maximum sourcing distance of 113 km (first scenario), 161 km (second scenario) and 209 km (third scenario). Then, the proposed network reconfiguration scenarios are transmitted to the organiser function. Greenfield analysis is used by the organiser to determine the DC facilities within the best geographical locations with different service constraints. The obtained results from GURU Software are displayed in Table 5.1 in which twelve, seven and four potential DC facilities with their assigned retailers are determined for first, second and third scenarios respectively. Figures 5.5-5.7 also displayed the screenshots of the GURU results for application to the reconfiguration scenarios.

Table 5. 1: Greenfield analysis results

	DC Facility	Latitude	Longitude	Number of assigned retailers
First Scenario	DC1	52.57657	-1.54377	65
	DC2	55.90237	-3.64298	30
	DC3	53.72346	-1.34595	35
	DC4	54.66324	-3.36845	11
	DC5	51.5389	0.14755	40
	DC6	51.60858	-3.66043	31
	DC7	52.41286	0.75166	15
	DC8	57.64985	-3.31961	3
	DC9	53.27981	-2.8974	65
	DC10	50.37546	-4.14266	5
	DC11	54.95469	-1.55084	23
	DC12	50.98893	-1.49658	17
Total	**12**			**340**
Second Scenario	DC Facility	Latitude	Longitude	Number of assigned retailers
	DC1	50.71858	-3.532	15
	DC2	55.6232	-2.81464	42
	DC3	53.58013	-2.09142	116
	DC4	51.48294	-0.38841	50
	DC5	52.24223	-3.37758	55
	DC6	56.4667	-2.9667	13
	DC7	52.5695	-0.24053	49
Total	**7**			**340**
Third Scenario	DC Facility	Latitude	Longitude	Number of assigned retailers
	DC1	50.71858	-3.532	42
	DC2	53.41493	-2.07702	161
	DC3	51.87856	-0.41942	90
	DC4	56.07189	-3.4537	47
Total	**4**			**340**

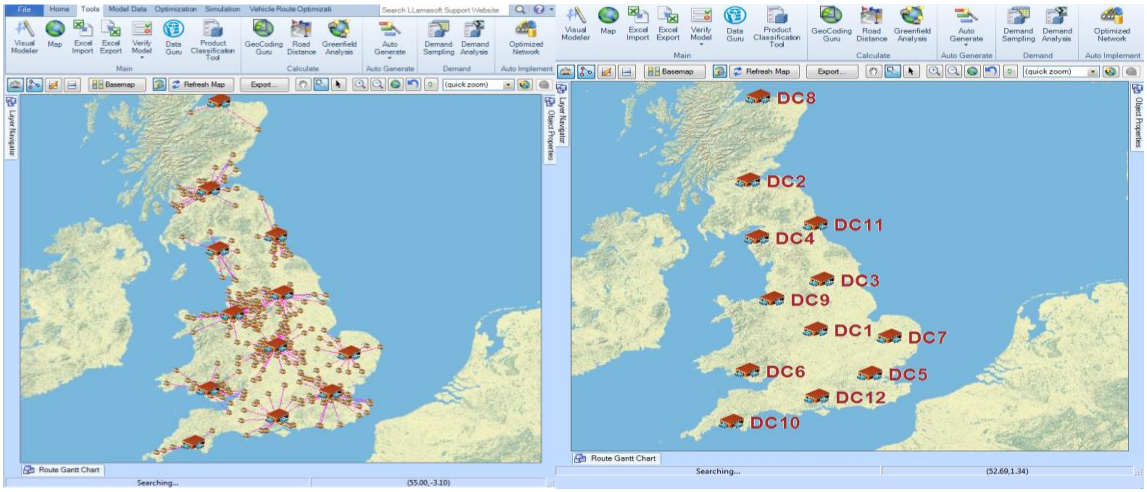


Figure 5. 5: Supply chain Guru Screen Shot of the Greenfield analysis result (First Scenario)

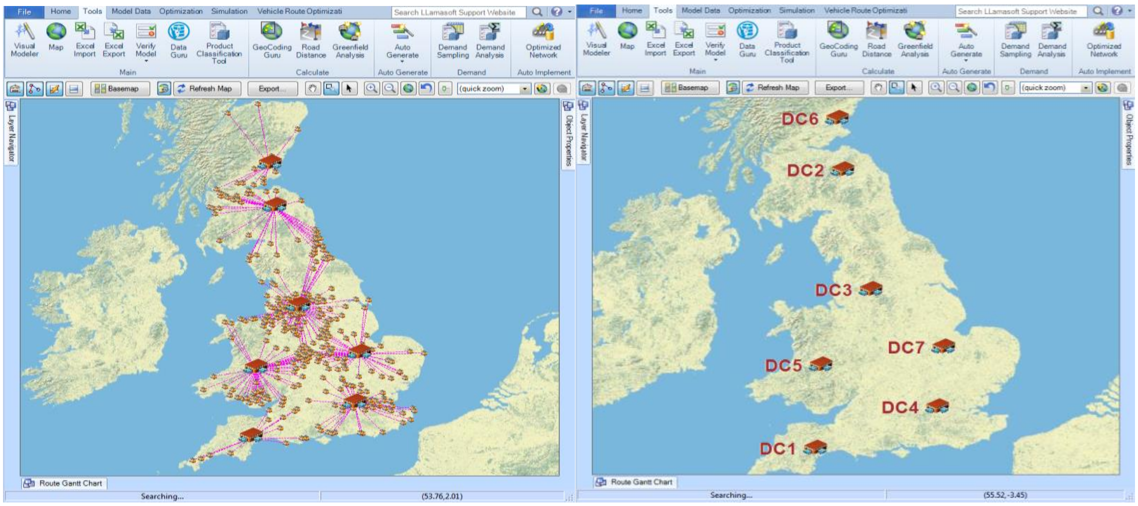


Figure 5. 6: Supply chain Guru Screen Shot of the Greenfield analysis result (Second Scenario)

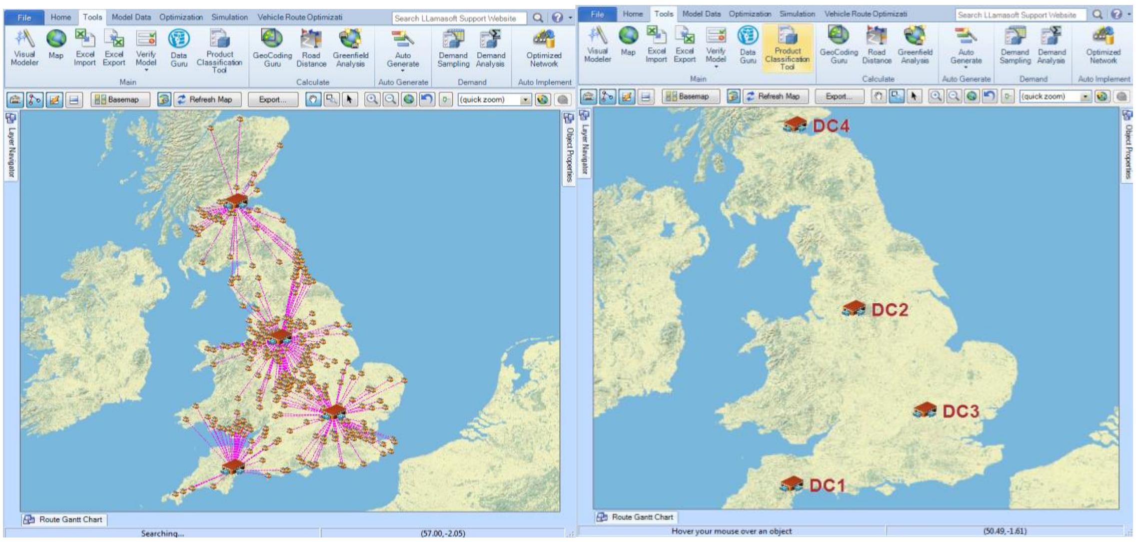


Figure 5. 7: Supply chain Guru Screen Shot of the Greenfield analysis result (Third Scenario)

5.4.1. Vehicle rout optimisation results

As soon as the configuration orders are received from the top level, resolvers in each bottom level notified the organisers to restructure the fractal to meet the orders. Then, in order to achieve the lowest CO_2 emission, the proposed green vehicle route optimisation in this paper is applied by resolvers to examine the different minimum shipment weights using the simulating annealing heuristics search which is programmed in MATLAB Software (See appendix 2). When the vehicle route optimisation, within the specified minimum shipment weight, is complete, performance measures are investigated by analysers located in the bottom level fractals and the analysis results are returned to the resolvers. The above loop between resolver and analyser is continued until an optimum shipment weight is found.

Table 5.2 demonstrates the green vehicle route optimisation results with split delivery through different scenarios which are obtained by determining the optimum minimum weight shipment.

Table 5. 2: Green vehicle route optimisation results

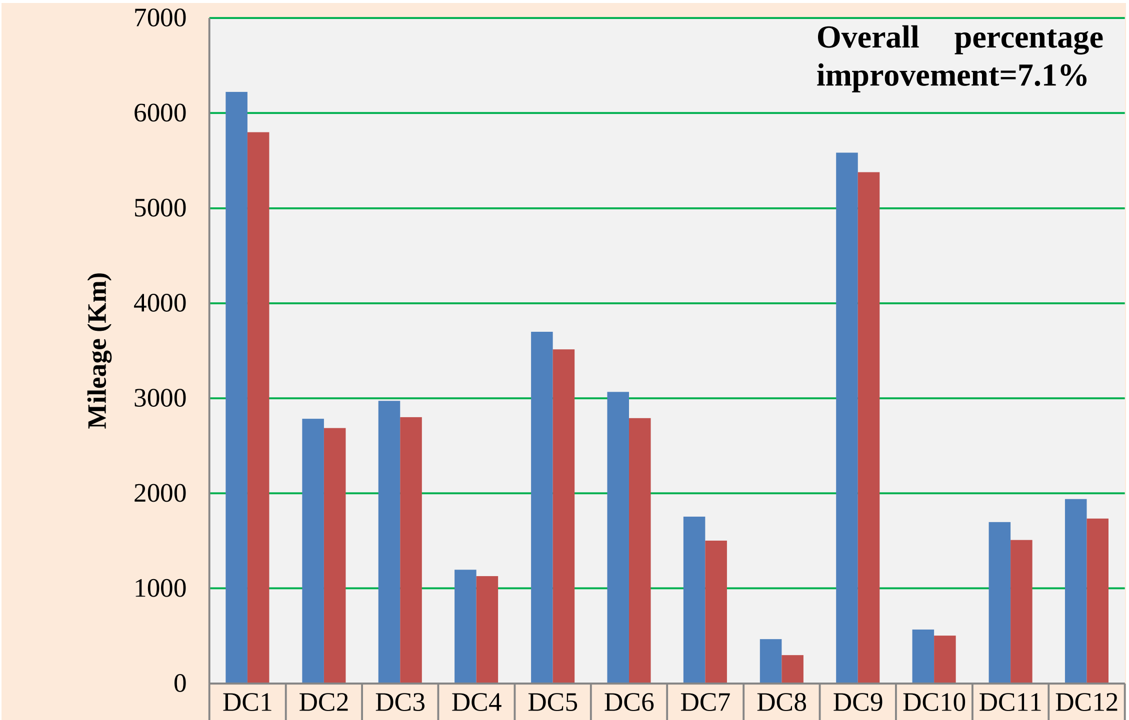
	DC Facility	optimum M_s(kg)	*C* (kg)	*TC* (£)	T_t (h)	*TNV* (Q)
First Scenario	DC1	1300	12868	12180	64	58
	DC2	1550	5970	5643	30	28
	DC3	1800	6286	5880	31	33
	DC4	1000	2523	2371	13	11
	DC5	1100	7649	7379	39	33
	DC6	1200	6247	5863	31	29
	DC7	900	3438	3158	17	14
	DC8	1300	706	628	3	3
	DC9	1300	12069	11294	60	60
	DC10	2000	1113	1061	6	5
	DC11	1000	3244	3173	17	22
	DC12	1400	3826	3641	19	14
Second Scenario	DC1	500	5942	5609	30	13
	DC2	1000	18023	16336	86	39
	DC3	900	29462	28020	148	100
	DC4	1100	13207	12590	67	42
	DC5	1300	20549	18753	99	52
	DC6	1600	3901	3715	20	13
	DC7	1100	16124	15028	80	44
Third Scenario	DC1	1000	20013	19236	102	37
	DC2	1500	55084	52582	278	150
	DC3	1400	34460	32645	173	85
	DC4	1030	19687	17993	95	44

*M_{sk}= Minimum shipment weight that must be on the vehicle along the each route during its service
*C = CO_2 emission
*TC = Transportation cost
*T_t = Transportation time
*TNV= Total number of required vehicles

In order to evaluate the efficiency of the proposed model, it was also tested without considering the minimum weight of shipments on board (M_{sk}) and results are compared with the proposed model outputs using two criteria: mileage and CO_2 emissions. Comparison of the results proved that in all scenarios, the obtained values from the proposed model are improved in terms of both mileage and CO_2 emission:

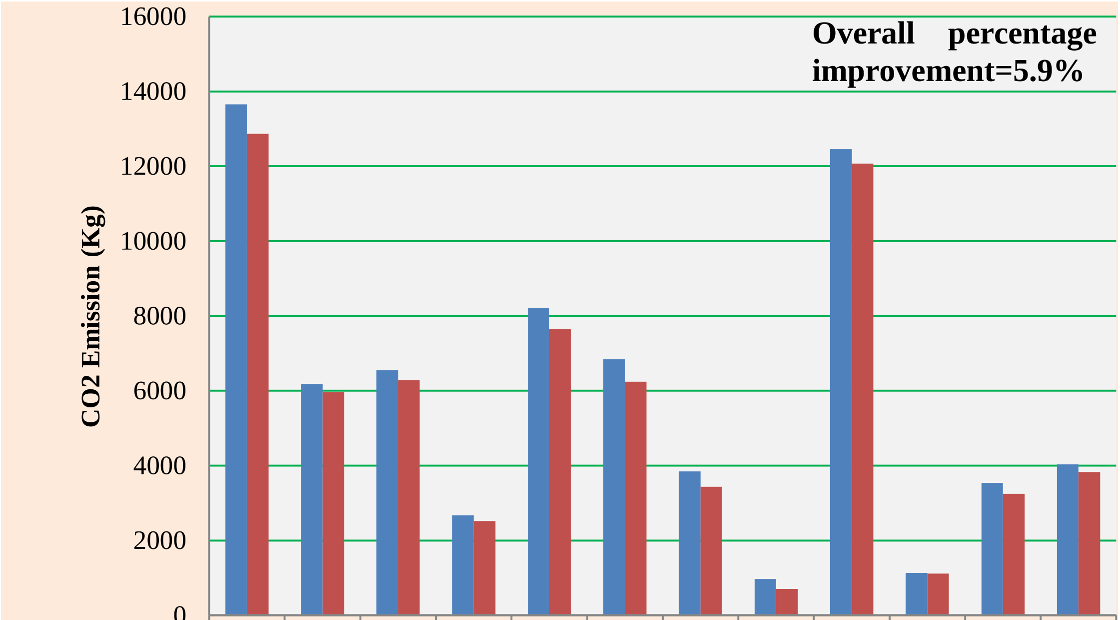
- In the first scenario, the values obtained from the proposed model in terms of both criteria, the mileage and CO_2 emissions were reduced by 7.1% and 5.9% respectively (see Figures 5.8 and 5.9).

- In the second scenario, figures 5.10 and 5.11 displays that there were also an improvement in both the mileage and CO_2 emissions by 7.4% and 4.9% respectively.
- Finally, both the mileage and CO_2 emissions were reduced by 4.9% and 3.3% in the third scenario as shown in figures 5.12 and 5.13.



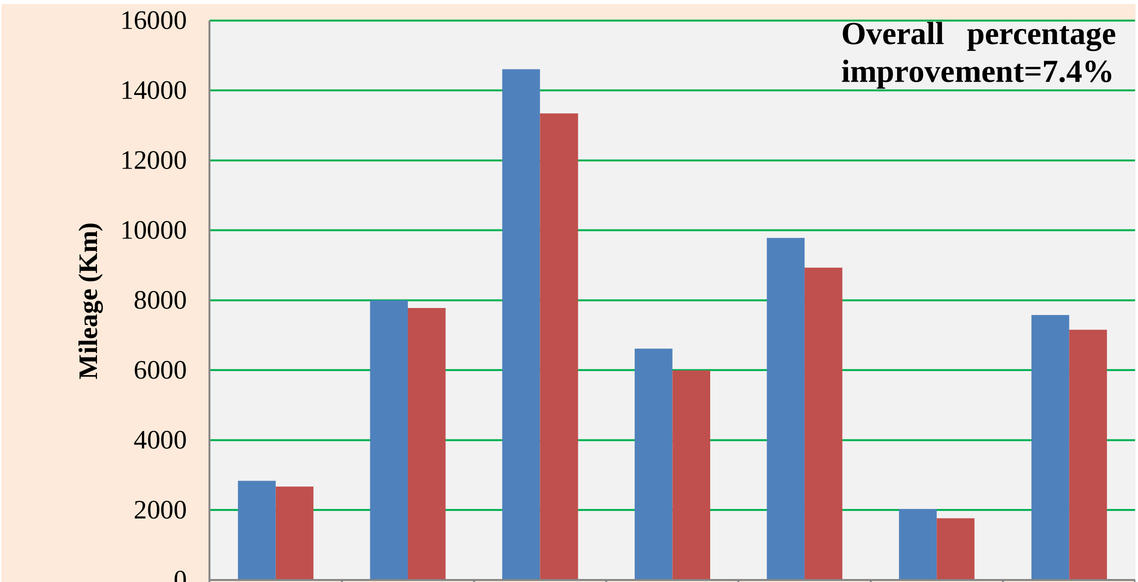
	DC1	DC2	DC3	DC4	DC5	DC6	DC7	DC8	DC9	DC10	DC11	DC12
Without Msk	6223	2786	2972	1196	3699	3067	1754	466	5585	566	1698	1940
With Msk	5800	2687	2800	1129	3514	2792	1504	299	5378	505	1511	1734

Figure 5. 8: Comparison of the generated results in terms of the mileage criterion in the first scenario



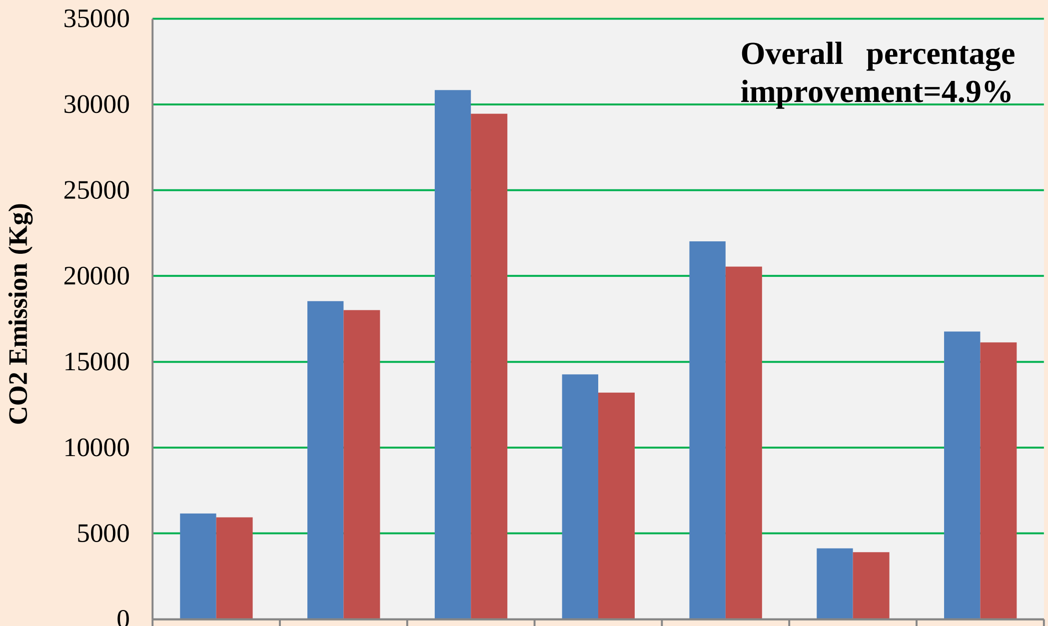
	DC1	DC2	DC3	DC4	DC5	DC6	DC7	DC8	DC9	DC10	DC11	DC12
Without Msk	13653	6180	6549	2674	8216	6840	3847	969	12460	1131	3543	4035
With Msk	12868	5970	6286	2523	7649	6247	3438	706	12069	1113	3244	3826

Figure 5. 9: Comparison of the generated results in terms of the CO_2 emission criterion in the first scenario



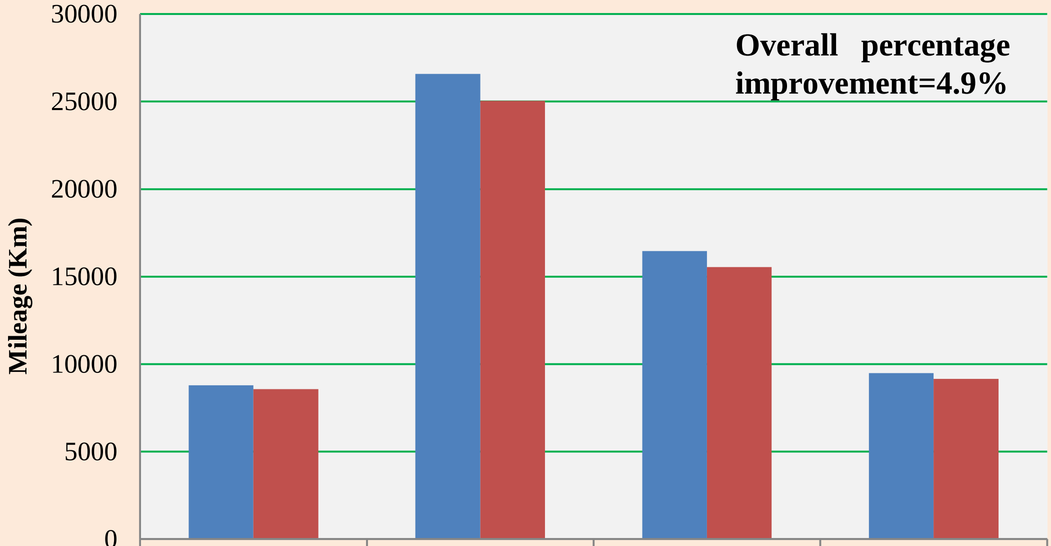
	DC1	DC2	DC3	DC4	DC5	DC6	DC7
Without Msk	2836	8000	14610	6613	9782	2033	7573
With Msk	2671	7779	13343	5995	8930	1769	7156

Figure 5. 10: Comparison of the generated results in terms of the mileage criterion in the second scenario



	DC1	DC2	DC3	DC4	DC5	DC6	DC7
Without Ms	6160	18540	30846	14262	22015	4128	16773
With Ms	5942	18023	29462	13207	20549	3901	16124

Figure 5. 11: Comparison of the generated results in terms of the CO_2 emission criterion in the second scenario



	DC1	DC2	DC3	DC4
Without Msk	8800	26572	16457	9490
With Msk	8568	25039	15545	9160

Figure 5. 12: Comparison of the generated results in terms of the mileage criterion in the third scenario

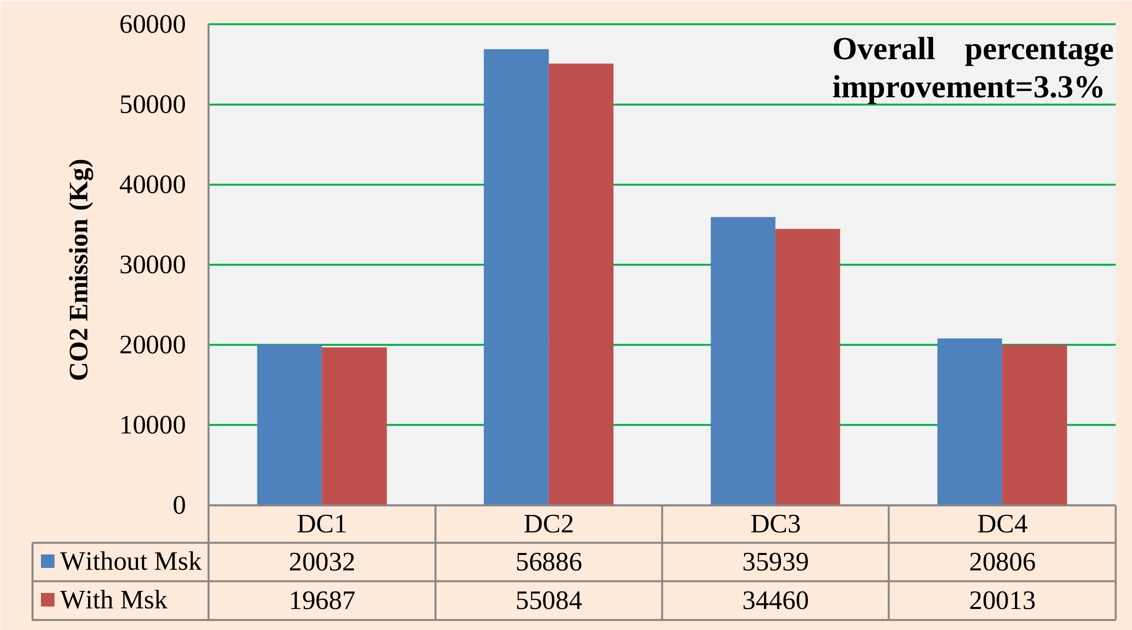


Figure 5. 13: Comparison of the generated results in terms of the CO_2 emission criterion in the third scenario

5.4.2. Distribution network sustainability analysis result

As soon as the results of implementing the reconfiguration scenarios are received from the bottom level, the analyser in the reconfiguration centre starts to investigate the network sustainability for each scenario and, in turn, the analyser outputs are transmitted to the resolver.

- *First Scenario*: The result proved that 310 units of transportation assets are required to meet stores demand and the total CO_2 emission, transportation costs and transportation time are 65,939 kg, £62,271 and 329 hours respectively.
- *Second Scenario*: The result showed that 303 units of transportation assets are required and total CO_2 emissions, transportation costs and transportation time are 107,208 kg, £100,050 and 529 hours respectively.
- *Third Scenario*: In terms of service constraint, with 100% of customer served within max sourcing distance of 209 km, 316 units of transportation assets are required for meeting the store's demand and total CO_2 emissions, transportation

costs and transportation time are 129,244 kg, £122,455 and 648 hours respectively.

In summary, as illustrated in Figure 5.14, CO_2 emissions, transportation costs and transportation time display rising trends from the first scenario to the third scenario, whilst, the number of required transportation assets to meet the store's demand to follow almost stable trends. Therefore, the Greenfield service constraint, with 100% of customers served within the maximum sourcing distance of 113 km is identified as the optimum scenario to have the lowest CO_2 emissions, transportation costs and transportation time.

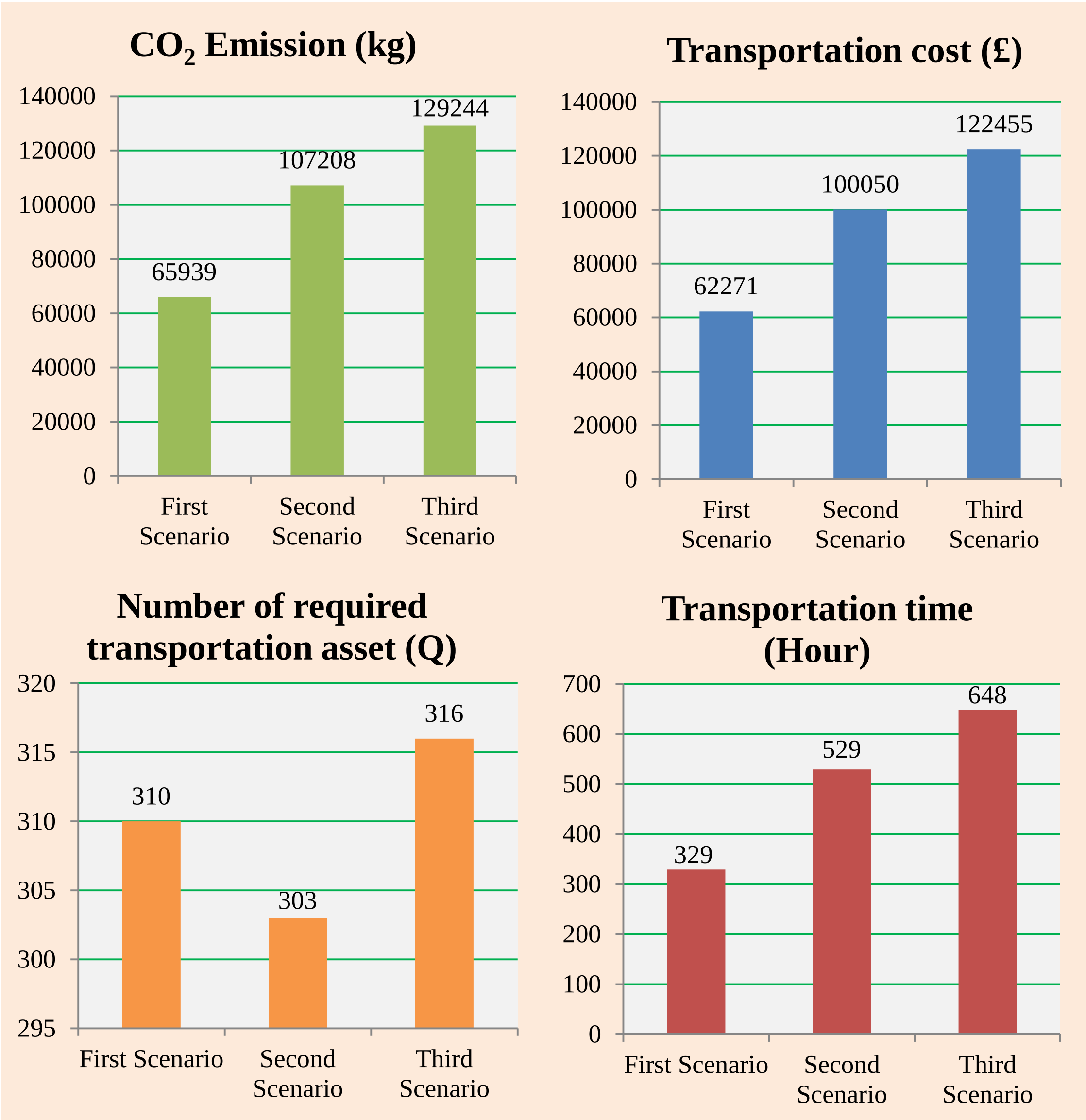


Figure 5. 14: Performance measures trends through reconfiguration scenarios

5.6. Conclusion

In this chapter, a new framework for the information fractal with two levels, named top and bottom level fractals, was proposed to optimise the food distribution network sustainability through two variables; Greenfield service constraints and the minimum weight of shipments on board.

The Fractal in the top level traced, observed and analysed the sustainability status of the distribution network, determined the optimum reconfiguration solution and, then, shared with fractals in the bottom level. Based on this information, the fractals in the bottom level implemented the reconfiguration orders and applied green vehicle route optimisation and then transmitted the sustainability performance information to the top-level fractal.

The proposed framework was applied to the hypothetical food distribution network. The Supply Chain GURU Software was adapted to implement the Greenfield analysis to identify the optimal number and location for setting up the new facilities. The new Green Split Delivery-Vehicle Route Problem (GSD-VRP) was developed and implemented using the simulated annealing algorithm which was programmed in the MATLAB software.

Application of the proposed framework has introduced a dynamic control system for the distribution network sustainability which has led to the increase of both collaboration and integration throughout the food distribution network.

Moreover, it provides a systematic method through which practitioners should be able to decide upon the optimal number and location of distribution facilities as well as optimal vehicle weight fill levels to improve the sustainability throughout food distribution chain.

The focus of this study was the environmental impact as one of the sustainability dimensions. However, for future work, the other dimensions of sustainability should be considered, and the proposed green vehicle route model should be developed further to take into consideration the time window, heterogeneous fleet and its availability for further evaluation and its effectiveness.

Chapter Six - Development of unique inventory control system for supply network

This chapter proposes unique inventory control system to increase both collaboration and integration and improve the process of sharing information across the network. Two Information Fractal Structure (IFS) frameworks for the optimisation of supply network inventory and which facilitate communication and collaboration between centralised Vendor-Managed-Inventory (VMI) and Just-In-Time production were developed respectively. They both proposed conceptual frameworks and hypothetical supply networks are implemented and validated using mathematical modelling and Supply Chain GURU Simulation Software to optimise the inventory in the supply network at the lowest logistics cost during the demand test period. Experimental factorial design and statistical techniques (MANOVA) are used to generate and analyse the results. Later in the chapter, the overall conclusion is presented.

6.1. The proposed framework for the Information Fractal Structure (IFS) to optimise inventory

Figure 6.1 displays the new proposed framework of an IFSN through the supply network with two levels including an *information fractal-centre* as a top-level fractal and the *information fractal-supplier's facility, information fractal-manufacturer*, *information fractal-distribution hub* and *information fractal-retailer* as bottom level fractals. For each of these information fractals, there are five function models namely: observer, analyser, resolver, organiser and reporter to form the basis of the information fractal unit structure.

Figure 6.2 demonstrates this structure and clearly explains the internal relationships amongst these five function models. Saad and Bahadori (2016) mentioned that observers in the sourcing fractals trace and receive the demand from the outer fractal gate, which could be a customer order; the observer transmits the demand data to analysers and notifies resolvers by receiving the demand at the same time. Analysers use an appropriate method to analyse current demands based on a set of demand statistics to determine demand class and, then, transmit it to resolvers. The demand class enables resolvers to recognise different types of demands and allocate an appropriate method to calculate safety stock. Resolvers determine the expected safety stocks and reorder points to optimise the safety stock. Organisers of all the fractals, including top and bottom level fractals; observe, control and manage the fractal structure to adapt to the continuous change in the environment. Reporters have a responsibility to report fractal outputs to outer fractals. In the bottom level fractal, reporters report resolvers' decisions regarding expected safety stock and reorder the point to the fractal in the top level.

In the top-level fractal, the observer traces and receives the decisions which are made by each fractal in the bottom level (e.g. Retailer), transmits them to analysers and then notifies resolvers. Analysers investigate and analyse the different replenishment frequencies on the transportation costs and inventory holding costs for each fractal in the bottom level. Resolvers integrate inventory holding costs and transportation costs based on analysers' reports to achieve an optimum replenishment frequency with the lowest logistics cost for each fractal in the bottom level. In the top-level fractal, reporters report resolvers' decisions regarding optimum replenishment frequency to the fractals in the bottom level. This research concentrates on two main functions, analyser and resolver, to optimise both the safety stock and replenishment frequency in the supply network.

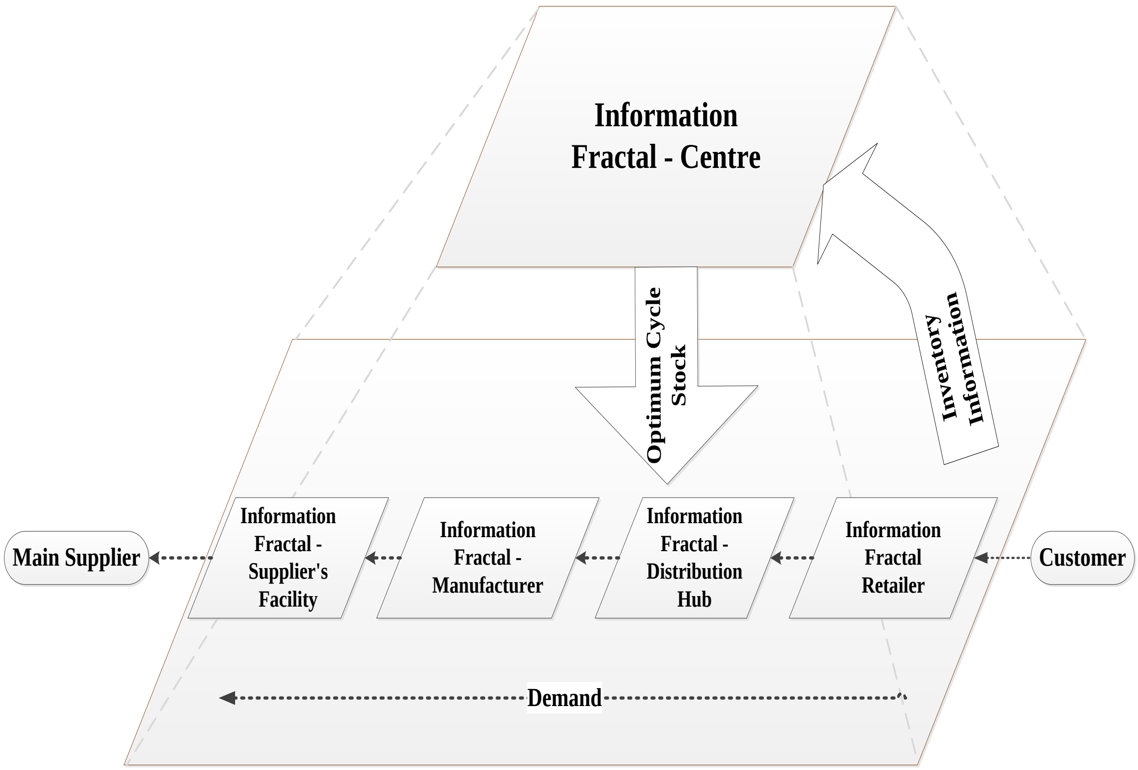


Figure 6. 1: The proposed framework for an information fractal supply network (IFSN)

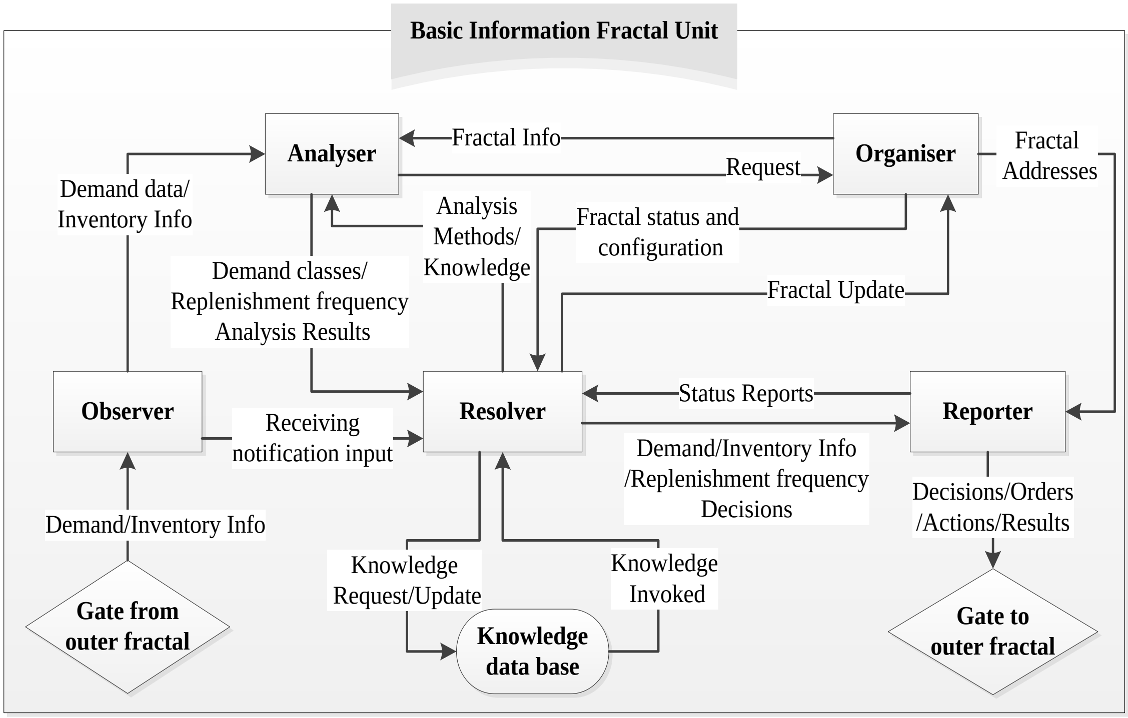


Figure 6. 2: Basic Information Fractal Unit Structure

6.1.1. Bottom level fractals

It is important to determine how much inventory must be held against the variability in both demand and lead times. Therefore, understanding the demand variability is essential to calculate safety stock. Analysers in the bottom level fractal use an appropriate method to analyse demand based on a set of demand statistics. During the demand analysis process, demand is aggregated, outliers are recognised, and a set of demand statistics are provided. Analysers use demand statistics and demand classification threshold values to determine the demand classification (e.g. Slow, Lumpy, Erratic and Smooth). Analysers perform the following steps to analyse current demand:

- Step 1: Determine aggregate demand for the specified aggregation period which can be based on a daily, weekly and monthly demand.
- Step 2: Provide a set of demand statistics to classify the demand (see Table 6.1).

Table 6. 1: Demand statistics parameters

Parameters	Description
Non-zero demand mean ($\boldsymbol{\mu_{NZ}}$)	Average size of demand during the period at the fractal which does not include aggregation periods with zero demand.
Non-zero demand standard division ($\boldsymbol{\sigma_{NZ}}$)	Standard deviation of demand during the period at the fractals in the bottom level fractal which does not include aggregation periods with zero demand.
Inter-demand interval mean ($\boldsymbol{p}$)	Average number of aggregation periods between two adjacent aggregated demand records in a time series.
Max non-zero demand (***D max***)	Demand with the largest size.
Squared coefficient variation of non- zero demand($\boldsymbol{CV^2_{NZ}}$)	The squared coefficient for the variation in demand size. This is the demand variability in relation to its mean. Non-zero demand CV^2 is derived as: (non-zero demand standard division /non-zero demand mean)^2
Non-zero demand count ($\boldsymbol{M_{NZ}}$)	The number of aggregation periods with non-zero demand
Di	Aggregated demand size
Daily Demand Mean ($\boldsymbol{\mu_d}$)	Average daily demand per aggregation period during the period at the fractal.
Daily Demand Std Dev ($\boldsymbol{\sigma_d}$)	Daily standard deviation of the aggregated demand during the period at the fractal.

- Step 3: Classifying demand based on demand statistics which are provided in step 2.

To set up a demand class, analysers use a set of demand classification thresholds that affect how demand is classified and how resolvers determine the appropriate approach for safety stock calculation. Demand classification thresholds include demand frequency, intermittency and dispersion which are determined by a non-zero demand count (M_{NZ}), inter-demand interval mean (p) and squared coefficient of variation of non-zero demand (CV^2_{NZ}), respectively. Outlier, variability and clumpiness are specified by a non-zero demand standard division (σ_{NZ}). Demand classification threshold values are determined based on the firm's conditions (see Figure 6.3).

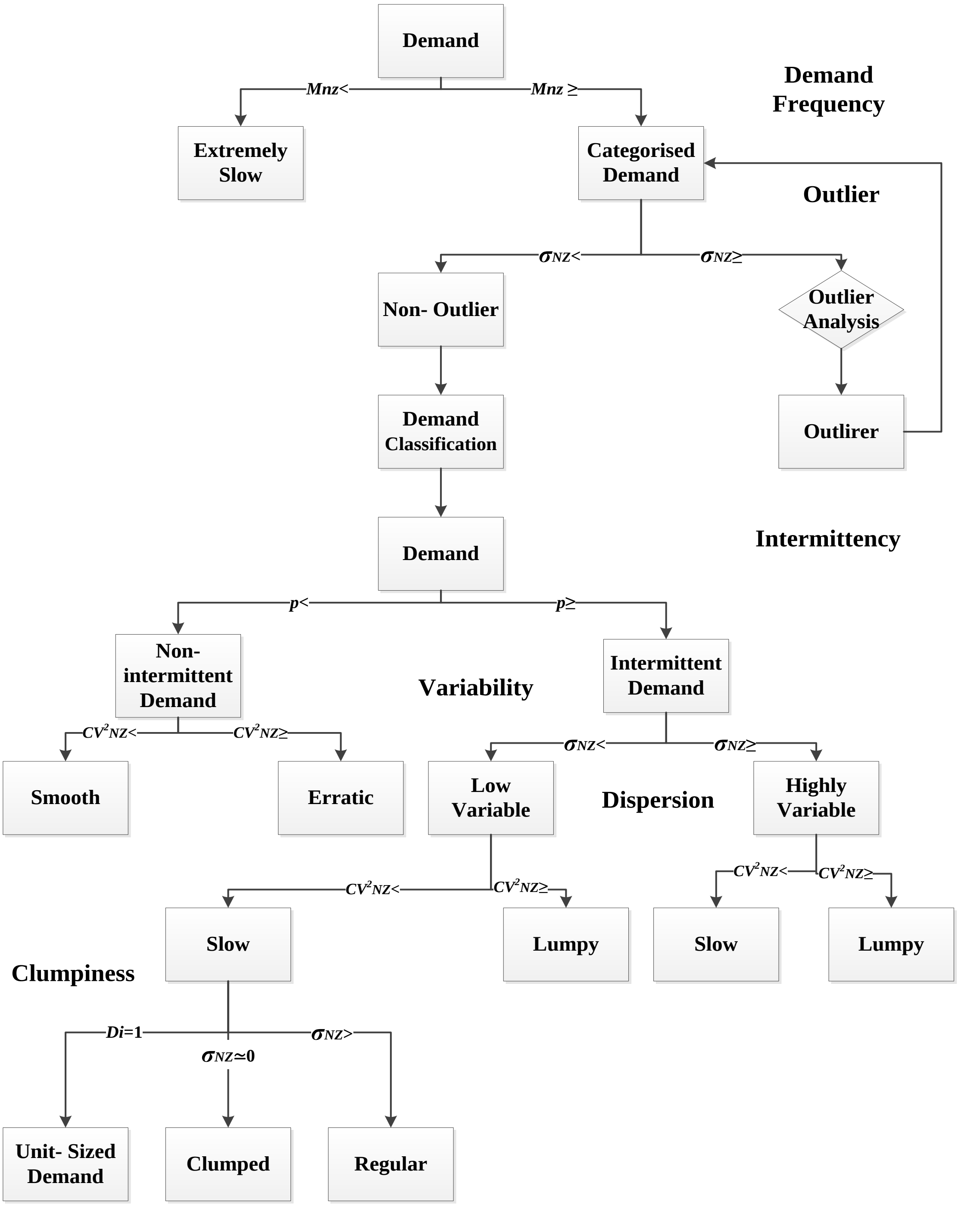


Figure 6. 3: Demand classification diagram

An extremely slow class will occur when the demand count is lower than the demand count adjusted in the demand classification thresholds. This class has a large inter-demand interval mean.

Analysers recognise outliers based on the non-zero demand standard division and the non-zero demand mean values during the demand classification process:

- If (σ_{NZ}) is less than the default number in the demand classification threshold, analysers ignore the outlier recognising process and continue to demand classification.
- If (σ_{NZ}) is greater or equal to the default number in the demand classification threshold, the outlier recognising process is initialised. Analysers looks at the aggregation period with the largest demand size (D_{max}) and determine it as an outlier if it is greater or equal to the product of multiplication of (σ_{NZ}) in the demand classification threshold and (μ_{NZ}) from the rest of the demand $\left(D_{max} \geq (\sigma_{NZ} \times \mu_{NZ})\right)$.

There are two options for analysers when handling the outliers:

- Outliers may be taken into consideration in the demand statistics where they were recognised.
- To replace outliers with the demand mean of the rest of the demands which are smaller than the outlier and recalculate the non-zero demand standard deviation and, then, return to the first step of the process.

Intermittency specifies how frequently demand occurs, based on the average time between adjacent demands.

- If the average time between the demands is lower than the intermittency threshold, it is known as non-intermittent demand. It means that demand happens regularly with a few exceptions during the demand period. If (CV^2_{NZ}) is greater than the default number in the threshold, this demand is classified as erratic and if (CV^2_{NZ}) is less, the demand is classified as smooth.

- If the average time between the demands is greater than the intermittency threshold, it is known as intermittent demand. It means that there is an irregularity of when the demand happens during the demand period. Intermittent demand can be considered a low or high variable and is slow or lumpy. Low variable demand has a lower (σ_{NZ}) in comparison to highly variable demand, and slow demand has a lower (CV^2_{NZ}) in comparison to lumpy demand.

Clumpiness shows how demand points are close to each other and clumped demand has a reasonably fixed demand with variability close to zero. The demand size for unit-sized demand is always one, and there is no variability for this demand class.

Once analysers have finished the demand analysis, resolvers start to specify the required safety stock by considering demand and lead-time variability. Resolvers use a target service level to calculate optimum safety stock. Service level is a measure to indicate a fractal's ability to provide products to downstream fractals. There are different types of service level which are used in industry, including type 1 (the probability of not stocking out), type 2 (fill rate) and type 3 (ready rate). In this research, service level type 1 is used. Resolvers in the bottom-level fractal determine the safety stock level and reorder points as part of the safety stock optimisation.

There are three models to calculate safety stock and reorder points which may happen during the demand period (Heizer & Render, 2014):

The following notations are adopted:

SS =Safety stock

σ_{dLT} = Standard division of demand during the lead time

σ_d= Standard deviation of demand per day

LT=Lead time

Z= Service level

ROP= Reorder point

μ_{dLT}= Demand mean during the lead time

μ_d= Average daily demand

d_D= Daily demand

σ_{LT}= Standard deviation of lead time in days

μ_{LT}= Average lead time

- Demand is variable, and lead time is constant:

$$SS = Z\sigma_{dLT} \tag{6.1}$$

Where:

$$\sigma_{dLT} = \sigma_d \times \sqrt{LT}$$

Then

$$SS = Z\left(\sigma_d \times \sqrt{LT}\right) \tag{6.2}$$

And

$$ROP = \mu_{dLT} + Z\sigma_{dLT} \tag{6.3}$$

Where:

$$\mu_{dLT} = \mu_d \times LT$$

Then

$$ROP = \mu_d \times LT + ZZ\left(\sigma_d \times \sqrt{LT}\right) \quad (6.4)$$

- Lead time is variable, and demand is constant:

$$SS = Z \times d_D \times \sigma_{LT} \quad (6.5)$$

And

$$ROP = (d_D \times \mu_{LT}) + Z \times \sigma_{LT} \quad (6.6)$$

- Both lead time and demand are variable:

$$SS = Z \times \sigma_{dLT} \quad (6.7)$$

Where

$$\sigma_{dLT} = \sqrt{(\mu_{LT} \times \sigma_d^2) + (\mu_d)^2 \times \sigma_{LT}^2}$$

Then

$$SS = Z\sqrt{(\mu_{LT} \times \sigma_d^2) + (\mu_d)^2 \times \sigma_{LT}^2} \quad (6.8)$$

And

$$ROP = (\mu_d \times \mu_{LT}) + Z \times \sigma_{LT} \tag{6.9}$$

6.1.2. Top level fractals

As part of the cycle stock optimisation in the supply network (Saad & Bahadori, 2015), the analysers of the fractals in the top level have to calculate the inventory holding costs for both components and products and analyse transportation costs by investigating different days between replenishment (*DBR* = *1,…, x*) during the demand period. Therefore, the mathematical relationship governing the problem of replenishment cycle stock, inventory holding costs and transportation costs are presented as follows respectively:

- To calculate replenishment cycle stock (*RCS*) in a supply network, analyser considers the days between replenishment (*DBR*); period time (*T*) and the flow quantity per period (*q*) from source fractal to destination fractal, which is the sum of the total demand and safety stock (see equations 6.10 and 6.11).

$$RCS = DBR \times \left(\frac{q}{2T}\right) \quad , DBR = 1, \dots, x \tag{6.10}$$

Where:

RCS= Replenishment cycle stock,

DBR = Days between replenishment,

q = Flow quantity per period,

T= Period time,

Where

$$q = \sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j$$

Where

TDj= Total demand of component *j*

j= Index number of different component/product

Then

$$RCS = DBR \times \left(\frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{2T} \right) \quad , DBR = 1, \dots , x \tag{6.11}$$

- The inventory holding cost of components/finished products in each fractal through supply network can be calculated using total inventory ($T_{(CI)}$) which is the sum of the safety stock (*SS*), replenishment cycle stock (*RCS*) and the in-transit inventory ($IT_{(CI)}$) where the in-transit inventory comprises components/products that are on order but have not arrived, component or product value (*V*), during a period time (*T*) and the percentage of inventory carrying cost ($I_{(cc)\%}$) (See equations 6.12 and 6.13).

$$IHC = T_{(CI)} \times V \times \frac{T}{365} \times I_{(cc)\%} \tag{6.12}$$

Where:

IHC =Inventory holding cost

$T_{(CI)}$ = Total inventory,

V = Component or product value,

$I_{(cc)\%}$ = Percentage of Inventory carrying cost

And

$$T_{(CI)} = SS + RCS + IT_{(CI)}$$

Where:

$IT_{(CI)}$ = In-transit inventory,

Where:

$$IT_{(CI)} = \frac{q \times t}{T}$$

Where:

t= Transportation time

Therefore,

$$IHC = \left\{ SS_j + DBR \times \left(\frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{2T} \right) + \frac{\left(\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j \right) t}{T} \right\} \times V \times \frac{T}{365} \times I_{(cc)\%} , DBR = 1, \dots, x \qquad (6.13)$$

- To calculate transportation cost ($T_{(c)}$); analysers determine the number of shipments (NOS) during the demand period between the source fractal and destination fractal by dividing the flow quantity (q) per period from source fractal to destination fractal to the replenishment quantity (RQ) (see equations 6.14 and 6.15).

$$NOS = \frac{q}{RQ} \tag{6.14}$$

Where:

NOS = Numbers of shipment,

RQ= Replenishment quantity,

And also:

$$RQ = DBR \times \mu_d \quad , DBR = 1, \dots, x$$

Then

$$NOS = \frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{DBR \times \mu_d} \quad , DBR = 1, \dots, x \tag{6.15}$$

As one of the fractal units, analysers use the number of shipments to specify the total travelling distance (T_{td}) from source fractal to destination fractal (see equations 6.16 and 6.17).

$$T_{td} = td \times NOS \tag{6.16}$$

Where:

T_{td} = Total travel distance,

td =Travel distance,

Then

$$T_{td} = td \times \frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{DBR \times \mu_d} \quad , DBR = 1, \ldots, x \tag{6.17}$$

Finally, transportation costs from source fractal and destination fractal are calculated using the following equations:

$$T_{(c)} = T_{td} \times A_{(C)} \tag{6.18}$$

Where:

$T_{(c)}$ = Transportation cost,

$A_{(c)}$ = Average transportation cost per mile.

Then

$$T_{(c)} = \left(td \times \frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{DBR \times \mu_d} \right) \times A_{(C)} \, , DBR = 1, \ldots, x \tag{6.19}$$

Since different numbers of days between replenishments (*DBR*) were investigated among fractals by the analyser, the resolver integrates both the inventory holding costs and transportation costs to achieve lower total logistics cost among fractals (see equation 6.20) to choose the best match and find the optimum amount of replenishment cycle stock.

$$Min\left\{\left[\left(SS_j + DBR \times \left(\frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{2T}\right) + \frac{\left(\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j\right) t}{T}\right) \times V \times \frac{T}{365} \times I_{(cc)\%}\right] + \left[\left(td \times \frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{DBR \times \mu_d}\right) \times A_{(C)}\right]\right\}, DBR = 1, \dots, x \qquad (6.20)$$

6.1.3. The application of the proposed information fractal structure using LlamaSoft

6.1.3.1. The hypothetical supply network

In this paper, we assume a supply network in the electronics industry. The main manufacturer (M) is located in Lyon, France and deals with different types of electronic devices which in this research comprises of just one type of laptop (with a value of $300 per product) made from different components. Components are supplied from seven suppliers (S) from different regions to the main manufacturer, including Japan (CD-ROM and RAM chip with values of $50 and $6 per component, respectively), Hong Kong (video cards and microprocessor with values of $20 and $30 per component, respectively), China (power supplier with a value of $10 per component), Malaysia (floppy drive with a value of $10 per component), Taiwan (cooling fan, monitor and network card with values of $4, $30 and $5 per component, respectively), Singapore (SCSI card and disk device with values of $8 and $30 per component, respectively) and Turkey (keyboard and soundcards with values of $15 and $20 per component, respectively). Due to long lead times from suppliers to manufacturer, each supplier built a facility (F) close to the manufacturer, located in Monaco, France, 219.3 miles away (Japanese facility); Barcelona, Spain, 388.34 miles away (Hong Kong facility); Nantes, France, 376.38 miles away (Chinese facility); Royan, France, 413.212 miles away (Malaysian facility); Agde, France, 212.51 miles away (Taiwanese facility); Genoa, Italy, 257.47 miles away (Singaporean facility) and Montpellier, France, 181.62 miles away (Turkish facility). Moreover, there are four distribution hubs (Dh), dealing with finished products located in Madrid, Spain (661.49 miles away) with two retailers (R) (Porto, Portugal and Malaga, Spain at 305.11 and 1062.79 miles distance, respectively); Paris, France (286.07 miles away) with two retailers (Tours, France and Ghent, Belgium at 152.84 and 187.89 miles distance, respectively); Milan, Italy (246.13 miles away) with three retailers (Bologna and Udine, Italy and Bern, Switzerland with 145.52, 154.07 and 233.11 miles distance, respectively) and Frankfurt, Germany (410 miles away) with four retailers (Bremen, Berlin and Homburg, Germany and Randers, Denmark at 238.68, 304.25, 298.86 and 284.38 miles distance, respectively).

6.1.3.2. Simulation modelling of the supply network

Figures 6.4 and 6.5 display screenshots of the supply chain GURU simulation model, created for the considered hypothetical supply network using LlamaSoft (2017). LlamaSoft allows an agent-based representation of the supply chain infrastructure and their behaviour and interactions while enabling a process-oriented approach to representing orders as in a discrete event simulation. Therefore, the agents here are the observer, analyser, resolver, organiser and reporter; however, as mentioned before, this research focuses on two main functions, analyser and resolver.

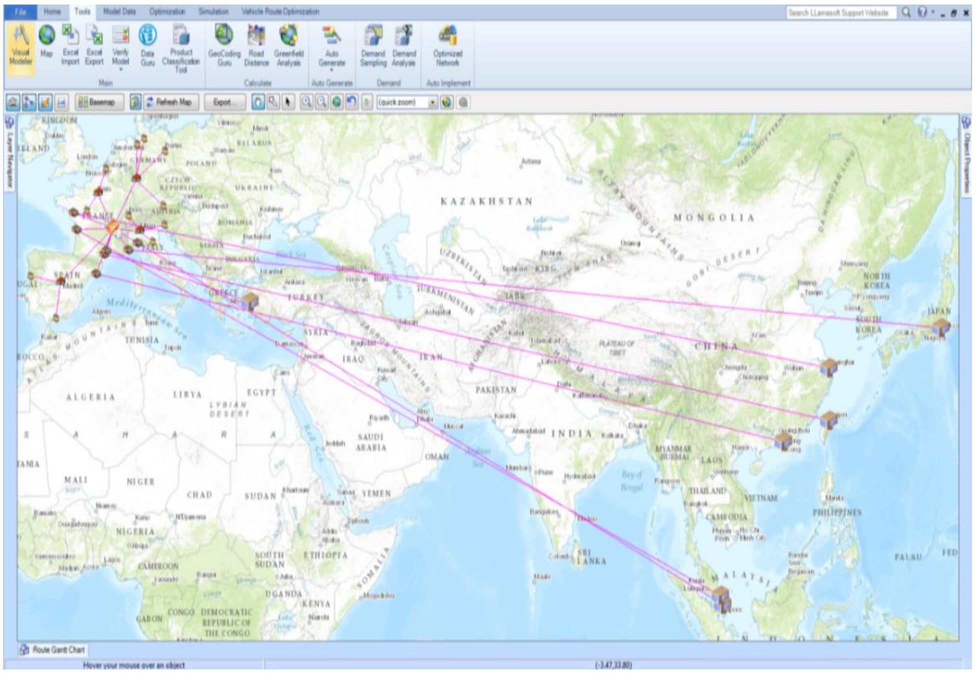


Figure 6. 4: Supply Chain Guru screenshot of the considered supply network

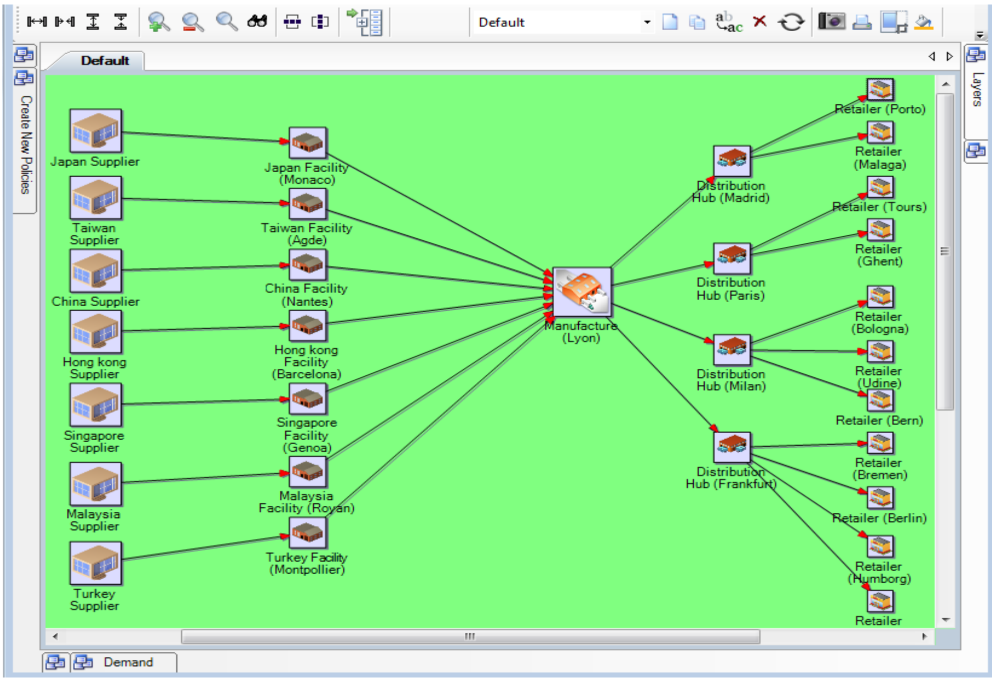


Figure 6. 5: Supply Chain Guru screenshot of a visual model of the considered supply network

The amount of demand quantity at each fractal in the bottom level is dictated by customer demand (e.g. retailers). The required level of inventory at each upstream fractal is determined by observing retailers' demand, and retailers' demand requirements are propagated through the multi-echelon network. Therefore, as shown in Table 6.2, random retailers' demand for the one type of product (laptop) during the period test of seven days (from 01/09/2016 to 07/09/2016) has been assumed.

Table 6. 2: Retailers' demand during a period of seven days

Retailer	**01/09/16**	**02/09/16**	**03/09/16**	**04/09/16**	**05/09/16**	**06/09/16**	**07/09/15**
Porto	719	734	1434	1926	1433	589	1097
Malaga	1265	1714	1619	1776	1344	1161	1028
Tours	831	966	421	855	1420	536	882
Ghent	1874	570	1753	1675	457	1698	1354
Bologna	595	1429	1096	582	697	771	1208
Odine	979	1967	1984	839	406	1612	1078
Bern	1538	774	1813	801	1122	590	1443
Bremen	907	1950	742	1221	558	1653	1814
Berlin	1479	893	419	620	1330	650	867
Homburg	1852	555	1058	1733	539	1576	1913
Randers	1073	1095	1381	1766	1020	744	1431

The lead time required for product and components to be replenished at the fractals from the upstream fractals is assumed to be eight days for the Malaysian facility, seven days for the Japanese, Hong Kong, Chinese, Taiwanese and Singaporean facilities, three days for the Turkish facility and two days for the main manufacturer, distribution hubs and retailers. Moreover, an average transportation cost per mile ($A_{(c)}$) and percentage of inventory carrying cost ($I_{(cc)\,\%}$) are assumed to be \$1 and 12 percent, respectively, and there is no limit for transportation assets in terms of capacity. The demand aggregation period was based on daily demand over seven days per week. In terms of demand outlier's determination, outliers were considered in the demand statistics when they were recognised. Moreover, demand classification threshold values were adjusted as default values (see Table 6.3 below).

Table 6. 3: Demand classification threshold values

Threshold	**Statistics used**	**Default Value**
Demand Frequency	Demand Count	3
Intermittency	Inter-Demand Interval Mean	1.32
Dispersion	Non-Zero Demand CV^2	0.49
Outlier	Non-Zero Demand Standard Deviation	10
Variability	Non-Zero Demand Standard Deviation	200
Clumpiness	Non-Zero Demand Standard Deviation	0.1

6.1.3.3. Experimental design

This section provides the design of experiments, which allow us to find out the impact of the uncertainties in the demand and the days between replenishment (*DBR*) on the performance of whole supply network, consisting of 22 sites including retailers, distribution hubs, main manufacture and supplier's facilities (see Figure 6.4). Four performance measures (dependent factors) namely transportation costs, inventory holding costs, cycle stock and total logistics costs are considered in this study.

After conducting pilot experiments, the two independent factors, with their levels, are identified and displayed in Table 6.4. Based on a full factorial experimental design, a total of 616 experiments are required to gather enough data and to allow the authors to draw a valid conclusion from this study.

Table 6. 4: Independent factors with their levels

Factor	**Levels**						
Demand	1000	Normal (1000,100)	Normal (1000,200)	Normal (1000,300)	-	-	-
(DBR)	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days

6.1.4. Results analysis and discussion

A full statistical factorial MANOVA technique was used to analyse the results obtained from GURU Simulation Software at 95% confidence interval. Table 6.5 displays the obtained results and the following can be concluded:

- Days between replenishment (*DBR*) and demand have a significant relationship with transportation costs, inventory holding costs, total logistics costs and cycle stock.
- Interaction of the days between replenishment and demand (*DBR * Demand*) show that there is a significant relationship with performance measures except for transportation cost.

Table 6. 5: Full factorial MANOVA results

Independent variables	Dependent variables	F	P	Significant
DBR	Transportation costs	110.008	.000< .005	Yes
	Inventory holding costs	215.503	.000< .005	Yes
	Total logistics costs	88.695	.000< .005	Yes
	cycle stock	50688297.593	.000< .005	Yes
Demand	Transportation costs	8.382	.000< .005	Yes
	Inventory holding costs	110.442	.000< .005	Yes
	Total logistics costs	91.323	.000< .005	Yes
	cycle stock	74342799.832	.000< .005	Yes
*DBR * Demand*	Transportation costs	.651	1.000>.005	No
	Inventory holding costs	3.505	.000< .005	Yes
	Total logistics costs	2.684	.000< .005	Yes
	cycle stock	4191481.369	.000< .005	Yes

6.1.4.1. Results analysis of bottom level fractal optimisation

According to the demand classification diagram (see Figure 6.3) and based on adjusted demand classification threshold values, as displayed in Table 6.3, analysers in the information fractals in bottom level classified the demand at different days between replenishment (*DBR*) from one day to seven days and the results obtained from GURU Software are presented in Table 6.6.

As can be seen, the classifications are as follows:

1) Smooth: when the average time between demand is less than intermittency p=1.32, the demand should be non-intermittent and, then, if (CV^2_{NZ} <0.49), the demand is finally classified as smooth.

2) Slow low variable: when the average time between demand is greater than intermittency p=1.32, the demand should be intermittent and if (σ_{NZ} < 200), the demand is characterised as a low variable, then is finally classified a slow low variable when (CV^2_{NZ}<0.49).

3) Slow high variable: when the average time between demand is greater than intermittency p=1.32, the demand should be intermittent and if (σ_{NZ} > 200), the demand

is characterised as a high variable, then is finally classified as a slow, low variable when (CV^2_{NZ}<0.49).

Table 6. 6: Demand class in the bottom level fractals at different DBR (1 day to 7 days)

Sites	1day	2days	3 days	4 days	5 days	6 days	7days
Porto (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Malaga (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Tours (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Ghent (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Bologna (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Odine (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Bern (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Bremen (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Berlin (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Homburg (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Randers (R)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Madrid (Dh)	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow Highly Variable
Paris (Dh)	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Milan (Dh)	Smooth	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Frankfurt (Dh)	Smooth	Smooth	Smooth	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable
Lyon (M)	Smooth	Smooth	Smooth	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable
Japan (F)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Hong Kong(F)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
China (F)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Malaysia (F)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Taiwan(F)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Singapore (F)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Turkey (F)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable

Since demand was variable and lead time was constant, resolvers used equations (6.2) and 6.4 to calculate the required safety stock with a service level of 0.95 percent and reorder points during the demand period test of seven days for each site. It has been noticed that the safety stock and the reorder points for all the retailers (Rs) are the same and do not change with the days between replenishment (*DBR*) (see Table 6.7 and 6.8)

Table 6. 7: Safety stock optimisation results in the bottom level fractals at different DBR (1 day to 7 days)

Sites	**Product / Component**	**1day**	**2days**	**3 days**	**4 days**	**5 days**	**6 days**	**7days**
Porto (R)	laptop	1139	1139	1139	1139	1139	1139	1139
Malaga (R)	laptop	674	674	674	674	674	674	674
Tours (R)	laptop	749	749	749	749	749	749	749
Ghent (R)	laptop	1366	1366	1366	1366	1366	1366	1366
Bologna (R)	laptop	774	774	774	774	774	774	774
Odine (R)	laptop	779	779	779	779	779	779	779
Bern (R)	laptop	1398	1398	1398	1398	1398	1398	1398
Bremen (R)	laptop	1064	1064	1064	1064	1064	1064	1064
Berlin (R)	laptop	1283	1283	1283	1283	1283	1283	1283
Homburg (R)	laptop	898	898	898	898	898	898	898
Randers (R)	laptop	1388	1388	1388	1388	1388	1388	1388
Madrid (Dh)	laptop	4692	5981	8779	10240	11511	12639	13652
Paris (Dh)	laptop	4273	5245	7682	8956	10063	11044	11924
Milan (Dh)	laptop	5260	6542	7971	11007	12416	13683	14839
Frankfurt (Dh)	laptop	6326	7746	9421	10876	12160	16010	17394
Lyon (M)	For each Component	29820	30014	30109	32334	36151	47871	51965
Japan (F)	CD-ROM RAM chip	115378	180304	225590	225180	180302	123542	123542
Hong Kong (F)	video cards microprocessor	115378	180304	225590	225180	180302	123542	123542
China (F)	power supplier	57689	90152	112795	112590	90151	61771	61771
Malaysia (F)	floppy drive	61673	95767	119810	119593	95766	65672	65672
Taiwan (F)	cooling fan monitor network card	173067	270456	338385	337770	270453	185313	185313
Singapore (F)	SCSI card disk device	115378	180304	225590	225180	180302	123542	123542
Turkey (F)	keyboard soundcards	75534	122840	153020	152752	122838	84086	84086

Table 6. 8: Reorder Point results in the bottom level fractals at different DBR (1 day to 7 days)

Sites	Product / Component	1day	2days	3 days	4 days	5 days	6 days	7days
Porto (R)	laptop	3405	3405	3405	3405	3405	3405	3405
Malaga (R)	laptop	3505	3505	3505	3505	3505	3505	3505
Tours (R)	laptop	2438	2438	2438	2438	2438	2438	2438
Ghent (R)	laptop	4047	4047	4047	4047	4047	4047	4047
Bologna (R)	laptop	2597	2597	2597	2597	2597	2597	2597
Odine (R)	laptop	3210	3210	3210	3210	3210	3210	3210
Bern (R)	laptop	3931	3931	3931	3931	3931	3931	3931
Bremen (R)	laptop	3372	3372	3372	3372	3372	3372	3372
Berlin (R)	laptop	3810	3810	3810	3810	3810	3810	3810
Homburg (R)	laptop	2686	2686	2686	2686	2686	2686	2686
Randers (R)	laptop	4024	4024	4024	4024	4024	4024	4024
Madrid (Dh)	laptop	9788	11078	13875	15336	16607	17735	18748
Paris (Dh)	laptop	8643	9614	12051	13325	14432	15413	16293
Milan (Dh)	laptop	12047	13328	14757	17793	19202	20469	21625
Frankfurt (Dh)	laptop	15586	17006	18681	20136	21420	25270	26654
Lyon (M)	For each Component	55333	55526	55622	57847	61663	73383	77477
Japan (F)	CD-ROM RAM chip	293966	358892	404178	403768	358890	302130	302130
Hong Kong (F)	video cards microprocessor	293966	358892	404178	403768	358890	302130	302130
China (F)	power supplier	146983	197817	202089	201884	179445	151065	151065
Malaysia (F)	floppy drive	163723	179446	221860	221643	197816	167722	167722
Taiwan (F)	cooling fan monitor network card	440949	538338	606267	605652	538335	453195	453195
Singapore (F)	SCSI card disk device	293966	358892	404178	403768	358890	302130	302130
Turkey (F)	keyboard soundcards	152072	199376	229556	229288	199374	160622	160622

6.1.4.2. Results analysis of top-level fractal optimisation

As part of the replenishment frequencies optimisation in the supply network, the analyser located in top-level fractal calculated the replenishment cycle stock (*RCS*), the inventory holding costs (*IHC*) and total transportation costs $T(c)$ for the fractals in the bottom level with different days of replenishment (from one day to seven) using equations (6.11), (6.13) and (6.19) - the results are reported in Tables 6.9 to 6.11.

Table 6. 9: Replenishment cycle stock results for the bottom level fractals at different DBR (1 day to 7 days)

Sites	Product / Component	1day	2days	3 days	4 days	5 days	6 days	7days
Porto (R)	laptop	648	1296	1944	2592	3240	3888	4536
Malaga (R)	laptop	756	1512	2267	3023	3779	4535	5291
Tours (R)	laptop	476	951	1427	1903	2379	2854	3330
Ghent (R)	laptop	768	1535	2303	3071	3838	4606	5374
Bologna (R)	laptop	511	1022	1533	2043	2554	3065	3576
Odine (R)	laptop	664	1327	1991	2654	3318	3981	4645
Bern (R)	laptop	733	1466	2199	2932	3665	4398	5132
Bremen (R)	laptop	653	1306	1960	2613	3266	3919	4573
Berlin (R)	laptop	723	1447	2170	2894	3617	4341	5064
Homburg (R)	laptop	511	1022	1533	2045	2556	3067	3578
Randers (R)	laptop	758	1516	2274	3033	3791	4549	5307
Madrid (Dh)	laptop	1739	3662	6092	8541	11130	13839	16652
Paris (Dh)	laptop	1549	3236	5376	7532	9811	12193	14666
Milan (Dh)	laptop	2283	4749	7430	10775	13971	17309	20772
Frankfurt (Dh)	laptop	3098	6398	9957	13691	17573	22737	27219
Lyon (M)	For each Component	10798	22333	35307	49777	65395	86594	105290

Table 6. 10: Inventory holding cost results for the bottom level fractal at different DBR (1 day to 7 days)

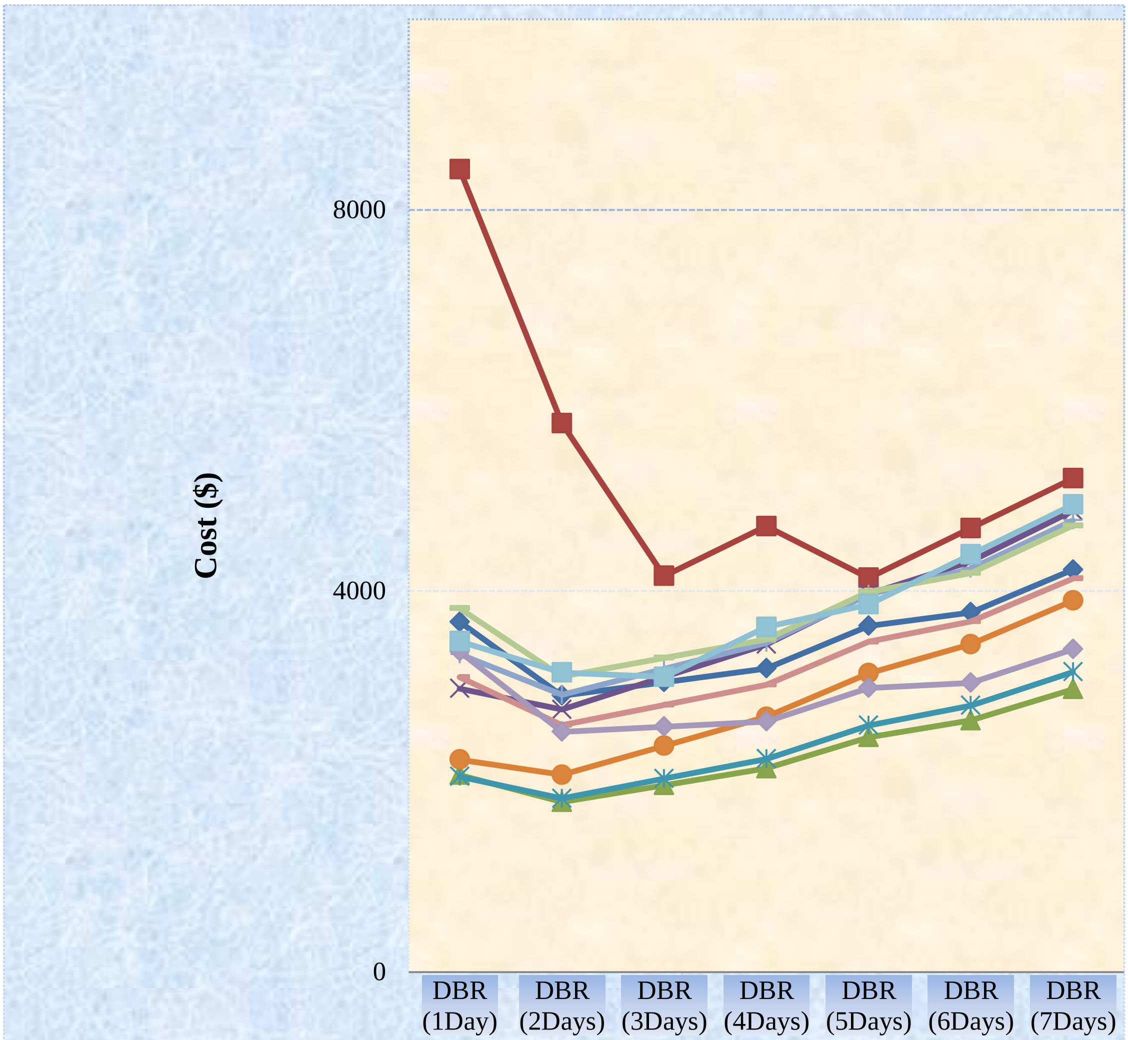
Sites	Product / Component	1day	2days	3 days	4 days	5 days	6 days	7days
Porto (R)	laptop	1234	1681	2128	2576	3023	3470	3918
Malaga (R)	laptop	987	1509	2031	2553	3074	3596	4118
Tours (R)	laptop	846	1174	1502	1831	2159	2488	2816
Ghent (R)	laptop	1473	2003	2533	3063	3593	4123	4653
Bologna (R)	laptop	887	1240	1592	1945	2298	2651	3003
Odine (R)	laptop	996	1454	1912	2370	2828	3286	3744
Bern (R)	laptop	1471	1977	2484	2990	3496	4002	4508
Bremen (R)	laptop	1186	1637	2088	2539	2990	3441	3892
Berlin (R)	laptop	1385	1885	2384	2884	3383	3883	4382
Homburg (R)	laptop	973	1326	1679	2032	2384	2737	3090
Randers (R)	laptop	1482	2005	2529	3052	3575	4099	4622
Madrid (Dh)	laptop	4440	6658	10267	12966	15631	18281	20922
Paris (Dh)	laptop	4019	5855	9016	11384	13721	16043	18358
Milan (Dh)	laptop	5208	7796	10633	15038	18218	21397	24586
Frankfurt (Dh)	laptop	6506	9765	13378	16961	20528	26751	30801
Lyon (M)	CD-ROM RAM chip	5235	6747	8430	10582	13087	17330	20266
Lyon (M)	video cards microprocessor	4674	6023	7527	9448	11685	15473	18095
Lyon (M)	power supplier	935	1205	1505	1890	2337	3095	3619
Lyon (M)	floppy drive	935	1205	1505	1890	2337	3095	3619
Lyon (M)	cooling fan monitor network card	3645	4698	5871	7370	9114	12069	14115
Lyon (M)	SCSI card disk device	3552	4578	5720	7181	8881	11760	13752
Lyon (M)	keyboard soundcards	3272	4216	5269	6614	8179	10831	12667

Table 6. 11: Total transportation costs among sites at different DBR (1 day to 7 days)

Source Site	Destination Site	1day	2days	3 days	4 days	5 days	6 days	7days
Madrid(Dh)	Porto(R)	2441	1220	915	610	610	305	305
Madrid(Dh)	Malaga(R)	7440	4251	2126	2126	1063	1063	1063
Paris(Dh)	Tours(R)	1223	611	459	306	306	153	153
Paris(Dh)	Ghent(R)	1503	752	564	376	376	188	188
Milan(Dh)	Bologna(R)	1164	582	437	291	291	146	146
Milan(Dh)	Odine(R)	1233	616	462	308	308	154	154
Milan(Dh)	Bern(R)	1865	932	699	466	466	233	233
Frankfurt(Dh)	Bremen(R)	1909	955	716	477	477	239	239
Frankfurt(Dh)	Berlin(R)	2434	1217	913	609	609	304	304
Frankfurt(Dh)	Homburg(R)	2391	1195	897	598	598	299	299
Frankfurt(Dh)	Randers(R)	1991	1138	569	569	284	284	284
Lyon (M)	Madrid(Dh)	5292	2646	1984	1323	1323	661	661
Lyon (M)	Paris(Dh)	2289	1144	858	572	572	286	286
Lyon (M)	Milan(Dh)	1969	985	738	492	492	246	246
Lyon (M)	Frankfurt(Dh)	3306	1653	1240	826	826	413	413
Japan(F)	Lyon (M)	3495	1553	1165	777	777	777	388
Hong Kong (F)	Lyon (M)	1913	850	638	425	425	425	213
China (F)	Lyon (M)	2317	1030	772	515	515	515	257
Malaysia (F)	Lyon (M)	1974	877	658	439	439	439	219
Taiwan (F)	Lyon (M)	1974	877	658	439	439	439	219
Singapore (F)	Lyon (M)	1635	726	545	363	363	363	182
Turkey (F)	Lyon (M)	3387	1506	1129	753	753	753	376

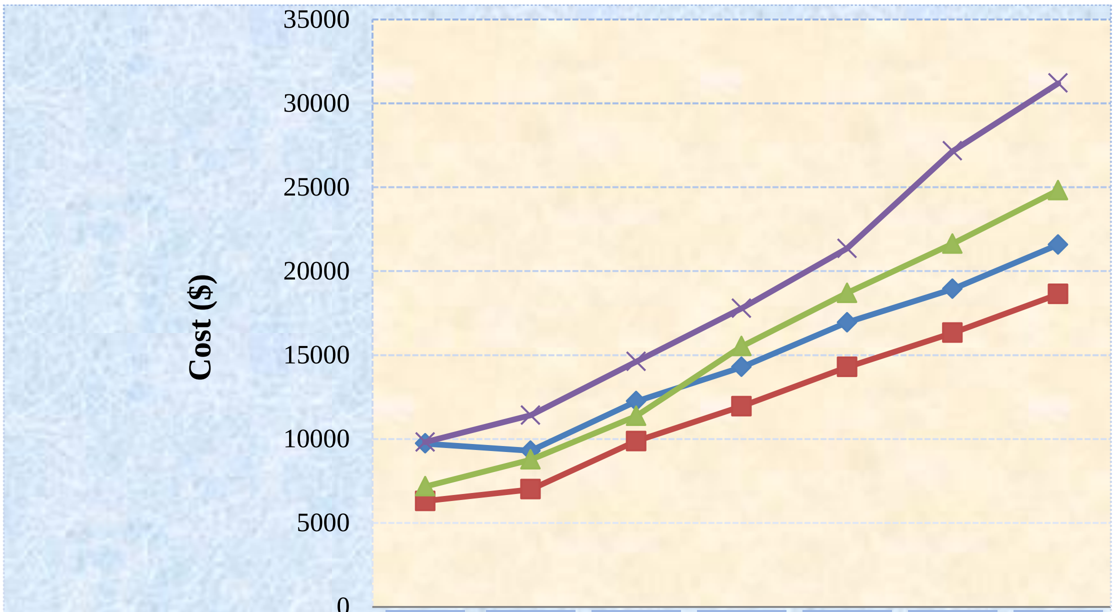
To achieve a lower total logistics cost throughout the supply network, the resolver uses the analyser results to integrate both inventory holding costs and transportation costs with respect to different days of replenishment among the fractals to choose the best match using equation (6.20).

The results proved that the days between replenishment (*DBR*) for the minimum total logistics cost between distribution hubs and retailers were two days, except for Madrid (Dh) to Malaga (R) and Frankfurt (Dh) to Randers (R) which were five and three days respectively (See figure 6.6). Figure 6.7 displays that the *DBR*, which resulted in a minimum total logistics cost between manufacturers and distribution hub was one day with the exception of Lyon (M) to Madrid (Dh) which was two days. Finally, figure 6.8 shows the reported minimum total logistics cost between the supplier facilities to the main manufacturer were two days between replenishment (*DBR*) apart from both Hong Kong (F) and Singapore (F) to Lyon (M).



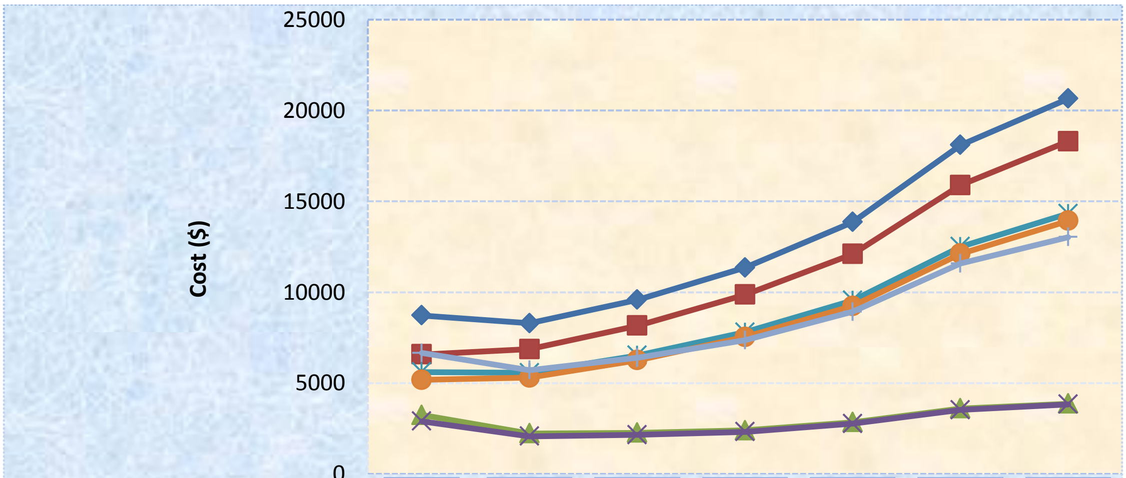
	DBR (1Day)	DBR (2Days)	DBR (3Days)	DBR (4Days)	DBR (5Days)	DBR (6Days)	DBR (7Days)
Madrid(Dh)→Porto(R)	3675	2901	3043	3186	3633	3775	4223
Madrid(Dh)→Malaga(R)	8427	5760	4157	4679	4137	4659	5181
Paris(Dh)→Tours(R)	2069	1785	1961	2137	2465	2641	2969
Paris(Dh)→Ghent(R)	2976	2755	3097	3439	3969	4311	4841
Milan(Dh)→Bologna(R)	2051	1822	2029	2236	2589	2797	3149
Milan(Dh)→Odine(R)	2229	2070	2374	2678	3136	3440	3898
Milan(Dh)→Bern(R)	3336	2909	3183	3456	3962	4235	4741
Frankfurt(Dh)→Bremen(R)	3095	2592	2804	3016	3467	3680	4131
Frankfurt(Dh)→Berlin(R)	3819	3102	3297	3493	3992	4187	4686
Frankfurt(Dh)→Homburg(R)	3364	2521	2576	2630	2982	3036	3389
Frankfurt(Dh)→Randers(R)	3473	3143	3098	3621	3859	4383	4906

Figure 6. 6: Total logistics cost at different DBR (1 day to 7 days) from distribution hubs to retailers



	DBR (1 Day)	DBR (2 Days)	DBR (3 Days)	DBR (4 Days)	DBR (5 Days)	DBR (6 Days)	DBR (7 Days)
Lyon(M)→Madrid(Dh)	9732	9304	12251	14289	16954	18942	21583
Lyon(M)→Paris(Dh)	6308	6999	9874	11956	14293	16329	18644
Lyon(M)→Milan(Dh)	7177	8781	11371	15530	18710	21643	24832
Lyon(M)→Frankfurt(Dh)	9812	11418	14618	17787	21354	27164	31214

Figure 6. 7: Total logistics cost at different DBR (1 day to 7 days) from the main manufacturer to distribution hubs



	DBR (1 Day)	DBR (2 Days)	DBR (3 Days)	DBR (4 Days)	DBR (5 Days)	DBR (6 Days)	DBR (7 Days)
Japan(F)→Lyon(M)	8730	8300	9595	11359	13864	18107	20654
Hong Kong(F)→Lyon(M)	6587	6873	8165	9873	12110	15898	18308
China(F)→Lyon(M)	3252	2235	2277	2405	2852	3610	3876
Malaysia(F)→Lyon(M)	2909	2082	2163	2329	2776	3534	3838
Taiwan(F)→Lyon(M)	5619	5575	6529	7809	9553	12508	14334
Singapore(F)→Lyon(M)	5187	5304	6265	7544	9244	12123	13934
Turkey(F)→Lyon(M)	6659	5722	6398	7367	8932	11584	13043

Figure 6. 8: Total logistics cost at different DBR (1 day to 7 days) from supplier facilities to the main manufacturer

6.2. The proposed framework for the Information Fractal Structure (IFS) to facilitate communication and collaboration between centralised VMI and JIT production

Figure 6.9 displays the proposed framework of the Information Fractal Structure (IFS) consists of an *"information fractal-core manufacturer"* with several of the information fractal work centres from the first step to final step of the production line and *"information fractal-centralised VMI"* with an information fractal VMI centre and information fractal supplier's facilities. For each of these information fractals, there are five function models namely: observer, analyser, resolver, organiser and reporter to form the basis of the information fractal unit structure (BFU) (Ryu et al., 2013) (see Figure 6.2).

Fractals in the core manufacture analyse the demand from next production step or customer, optimise their safety stock and determine the optimal reorder point and share their demand and inventory information with the source fractal (see Section 6.1.1).

Subsequently, the information fractal VMI centre traces and observes manufacturer's components demand and inventory information from work centres which are located in the first step of the production lines. Then, share the components demand with supplier's facilities and scheduling replenishment quantity-frequency based on optimum replenishment cycle stock to core manufacturer. Both inventory holding cost in the core manufacturer and transportation cost from centralised VMI to core manufacturer are optimised aiming to minimise the logistics costs and share them with first step work centres (see Section 6.1.2).

Information fractal supplier's facilities trace, observe and analyse demand from VMI centre, optimise safety stock and determine the optimal reorder point and share inventory information with their main suppliers and information fractal VMI centre.

This research concentrates on two main functions, analyser and resolver, to facilitate communication and collaboration between centralised Vendor-Managed-Inventory (VMI) and Just-In-Time production to optimise inventory and logistics cost in the supply network.

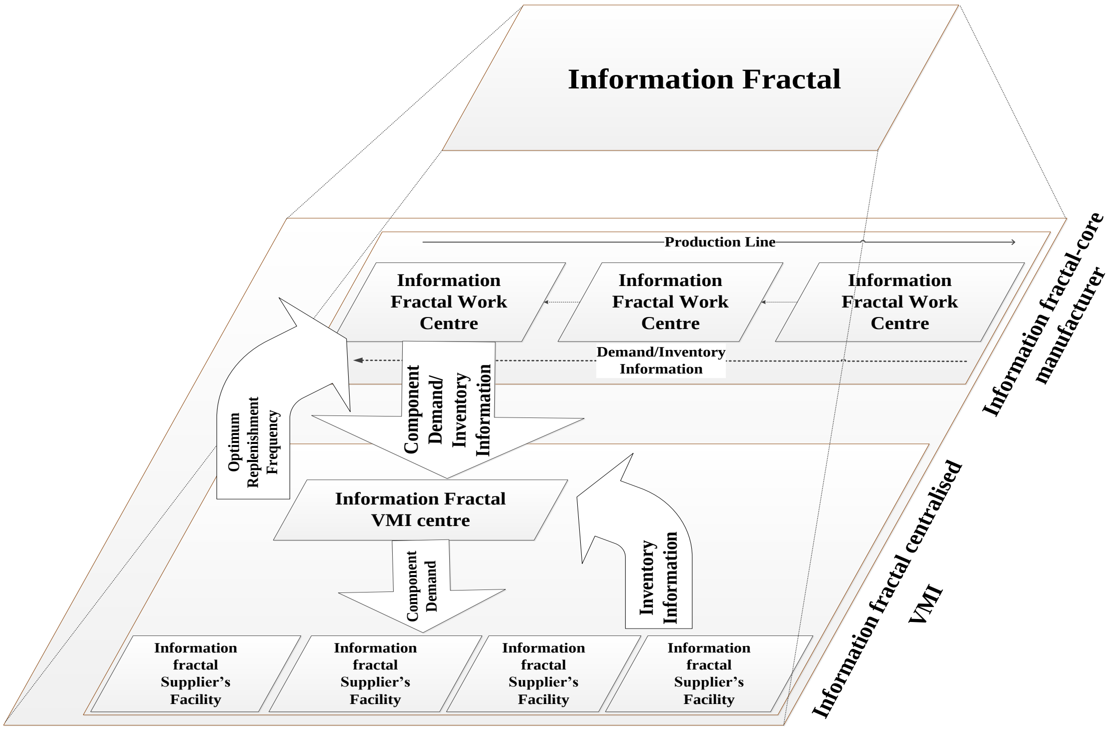


Figure 6. 9: Information Fractal Structure (IFS)

6.2.1. Application of the proposed information fractal structure

6.2.1.1. The hypothetical supply network

To apply the proposed structure, a hypothetical supply network and its data is considered with a core manufacturer located in the San Antonio, Texas, USA, five distribution centres (DC1, DC2, DC3, DC4 and DC5) were used to distribute the products around the country. The centralised VMI was located in the Corpus Christi, Texas, USA and five worldwide suppliers were located in Venezuela, Senegal, Portugal, Japan and South Korea. These were considered and implemented in the Supply Chain Guru Simulation Software.

The manufacturer deals with three different products (K_1, K_2 and K_3) which are produced by three production lines (A, B, and C) respectively as shown in figure 6.10 where:

- Production line A consists of three different centres, namely cutting centre (A), assembly centre (A) and packaging centre (A) to produce K_1.
- Production line B comprises two different centres which are assembly centre (B) and packaging centre (B) to produce K_2.
- Production line C made up of four different centres; cutting centre (C), assembly centre (C), Dyeing centre (C) and packaging centre (C) to produce K_3.
- The input and output of each centre in the production lines A, B, and C are shown in the following table 6.12.

Table 6. 12: The input and output of centres in the different production lines

Production line name	**Centre name**	**Input name**	**Output name**
Production line A	Cutting centre (A) Assembly centre (A) Packaging centre (A)	Components (a, c and e) Part $_{CA}$ Part $_{AA}$	Part $_{CA}$ Part $_{AA}$ Product K_1
Production line B	Assembly centre (B) Packaging centre (B)	Components (b and d) Part $_{BA}$	Part $_{BA}$ Product K_2
Production line C	Cutting centre (C) Assembly centre (C) Dyeing centre (C) Packaging centre (C)	components (a, b, c, d and e) Part $_{CC}$ Part $_{AC}$ Part $_{DC}$	Part $_{CC}$ Part $_{AC}$ Part $_{DC}$ Product K_1

The centralised VMI has been built closer to the main manufacturer (150 miles from core manufacturer) and comprises of five supplier's facilities (Venezuela's facility, Senegal's facility, Portugal's facility, Japan's facility and South Korea's facility) belonging to worldwide suppliers in which:

- Venezuela's facility deals with a single component (a) with a value of $10.
- Senegal's facility deals with a single component (b) with a value of $50.
- Portugal's facility deals with a single component (c) with a value of $20.
- Japan's facility deals with a single component (d) with a value of $ 60.
- South Korea's facility deals with a single component (e) with a value of $10.

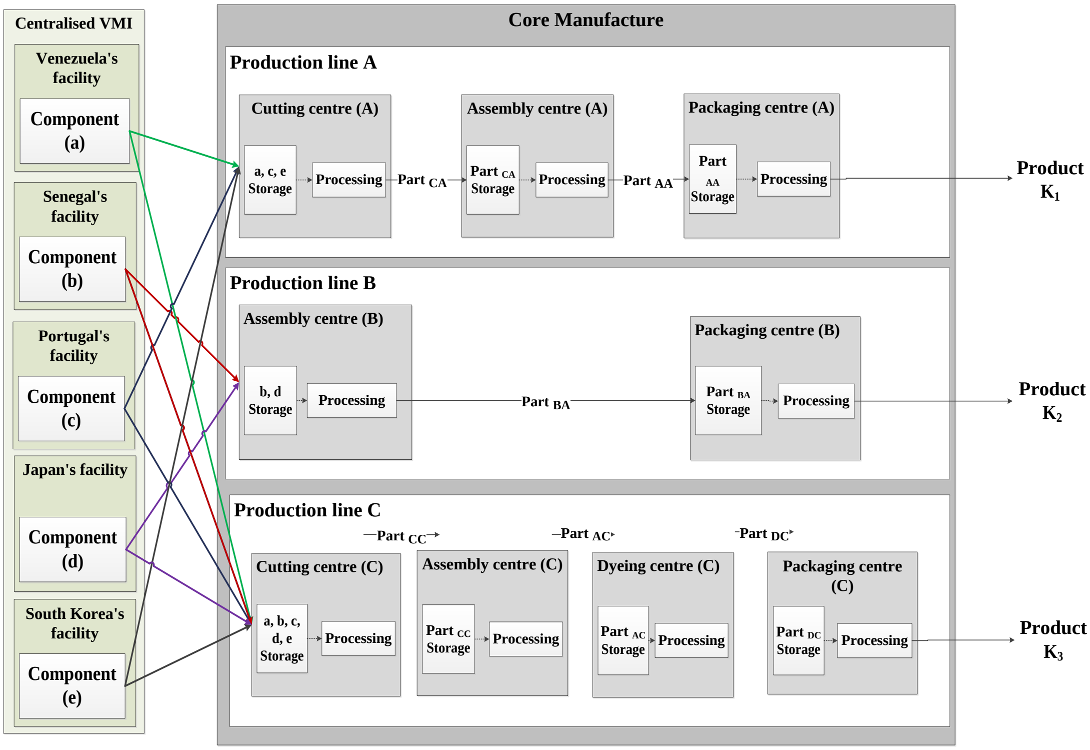


Figure 6. 10: Centralised VMI, core manufacturer structure, components and parts flow mapping

6.2.1.2. Simulation modelling of the supply network

Figure 6.11 displays a screenshot of the GURU model, created for the considered hypothetical supply network using LlamaSoft (2017). As already mentioned in section 6.1.3, LlamaSoft allows an agent-based representation of the supply chain infrastructure and their behaviour and interactions while enabling a process-oriented approach to representing orders as in a discrete event simulation.

Therefore, the agents here are the observer, analyser, resolver, organiser and reporter; however, only two main functions, analyser and resolver are considered.

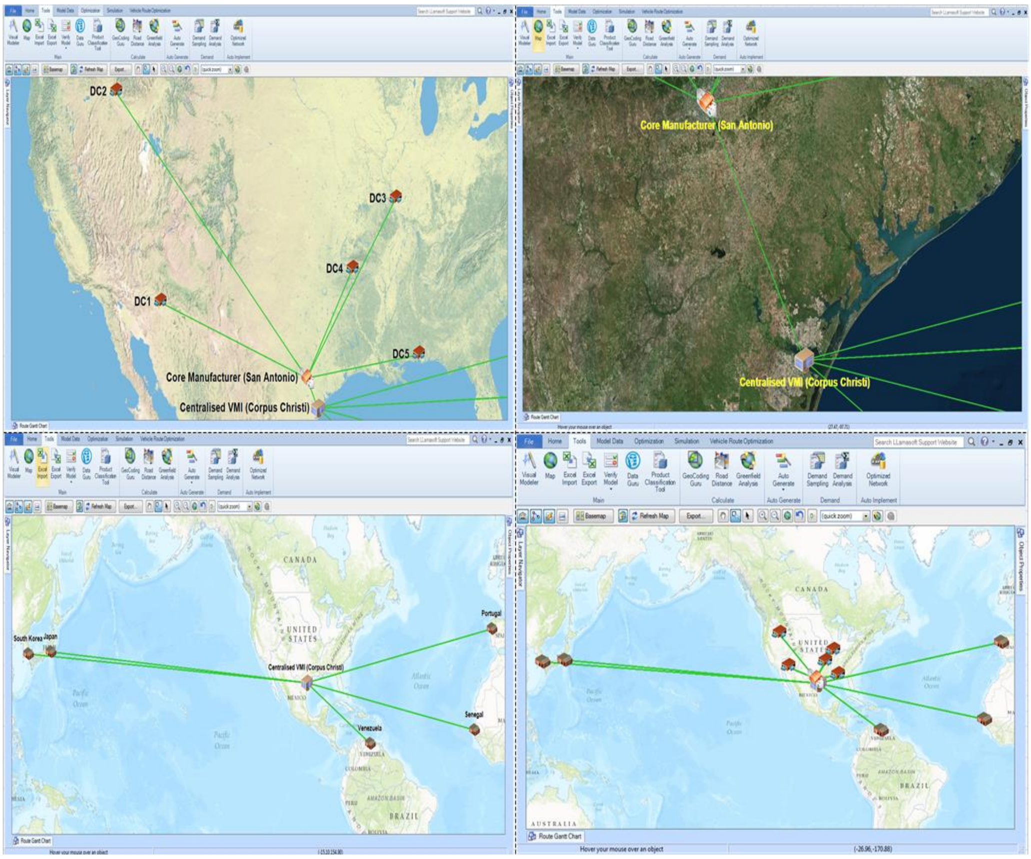


Figure 6. 11: Supply chain Guru Screen Shot of the considered supply network

The distribution centre's demand for a one-month test period for the three types of products (K_1, K_2 and K_3) has been recorded as shown in Table 6.13.

Table 6. 13: Distribution centre's demand of one-month test period

Distribution Hub	Product	Order due to 31/08/2016	Order due to 07/09/2016	Order due to 14/09/2016	Order due to 21/09/2016	Order due to 28/09/2016
DC1	K_1	300	330	400	330	160
	K_2	500	444	263	495	343
	K_3	420	455	463	152	328
DC2	K_1	250	400	350	370	150
	K_2	156	415	482	370	347
	K_3	250	218	500	356	443
DC3	K_1	220	180	270	420	200
	K_2	260	454	444	278	246
	K_3	254	159	217	401	477
DC4	K_1	320	220	400	470	220
	K_2	350	156	154	270	400
	K_3	300	477	244	263	418
DC5	K_1	260	200	460	500	240
	K_2	150	414	345	176	393
	K_3	450	387	180	252	345

In addition, there are some other assumptions listed below and obviously we should review the obtained results within the domain of these assumptions, which may represents some limitations that can be considered as part of future work.

- The lead time required for components (a), (b), (c), (d) and (e) to be replenished at the supplier's facilities in the centralised VMI is assumed to be 20 days for (Venezuela's facility, Senegal's facility and Japan's facility), and 21 days for (Portugal's facility and South Korea's facility).
- The lead time required to supply components from centralised VMI to core manufacturer and parts among centres in the manufacturer is fixed to be 1 day.
- The percentage of inventory carrying cost is assumed to be 12 percent of the total value of inventory. In practice, this percentage is identified by senior managers in the company.
- There is a transportation system from a third party with two types of transportation assets to ship components from centralised VMI to core manufacturer, namely; Full truckload (TL) with capacity of more than 2000 components (up to 7000 components) with Average transportation Cost per mile ($A_{(c)}$) of \$1 and Less than Truck Load (LTL) with capacity of less than 2000 components with average transportation cost per mile ($A_{(c)}$) of \$1.5.
- The days between replenishment (*DBR*) should not be more than 5 days.
- The demand aggregation period is based on weekly demand over seven days per week.
- In terms of demand outliers' determination, outliers were considered in the demand statistics when they were recognised.
- The demand classification threshold values were adjusted as default values (see Table 6.4).

6.2.1.1. Experimental design

This section provides the design of experiments which allow us to find out the impact of the uncertainties in the demand, days between replenishment (*DBR*) and component demand mix based on the performance of centralised VMI and core manufacturer which consisted of the three production lines as shown in figure 6.10. Four performance measures (dependent factors) namely transportation cost, inventory holding cost, cycle stock and total logistics cost are considered in this study.

After conducting pilot experiments, the three independent factors with their levels are identified and displayed in Table 6.14. Based on full factorial experimental design, a total of 60 experiments are required to gather enough data and to allow the author to draw a valid conclusion from this study.

Table 6. 14: Independent factors with their levels

Factor	**Levels**				
Demand	1000	Normal (1000,100)	Normal (1000,200)	Normal (1000,300)	-
(*DBR*)	1 Day	2 Days	3 Days	4 Days	5 Days
Component Demand Mix	$\sum_{j=1}^{3} SS_j + \sum_{j}^{3} TD_j$	$\sum_{j=1}^{2} SS_j + \sum_{j}^{2} TD_j$	$\sum_{j=1}^{5} SS_j + \sum_{j}^{5} TD_j$	-	-

6.2.2. Results analysis and discussion

A full statistical factorial MANOVA technique was used to analyse the results obtained from GURU Simulation Software at a 95% confidence interval. Since, in this case, demand and demand mix were dependent on each other; demand factor has been used as a co-variate variable. Table 6.15 displays the obtained results and the following can be concluded:

- Days between replenishment (*DBR*) has a significant relationship with transportation costs, inventory holding costs, total logistics costs and cycle stock.

- *Demand* and *component demand mix* has a significant relationship with inventory holding costs and total logistics costs, however, it is apparent that both transportation and cycle costs are not significantly affected by the demand or demand mix.
- The interaction between days between replenishment and Component demand mix (*DBR * Component Demand Mix)* show that there is a significant relationship with performance measures except for transportation cost.

Table 6. 15: Full factorial MANOVA results

Dependent variables	Independent variables	F	P	Significant
DBR	Transportation costs	568.121	.000< .005	Yes
	Inventory holding costs	29.374	.000< .005	Yes
	Total logistics costs	9.370	.000< .005	Yes
	cycle stock	92.502	.000< .005	Yes
Demand	Transportation costs	.057	.813> .005	No
	Inventory holding costs	83.391	.000< .005	Yes
	Total logistics costs	82.220	.000< .005	Yes
	cycle stock	1.068	.307> .005	No
Demand Mix	Transportation costs	.368	.694>.005	No
	Inventory holding costs	307.337	.000< .005	Yes
	Total logistics costs	283.149	.000< .005	Yes
	cycle stock	.304	.739> .005	No
*DBR * Component Demand Mix*	Transportation costs	.611	.764>.005	No
	Inventory holding costs	6.908	.000< .005	Yes
	Total logistics costs	6.577	.000< .005	Yes
	cycle stock	9.572	.000< .005	Yes

6.2.2.1. Demand analysis by the "Analysers" in the Information fractal

As part of demand analysis and according to the demand classification diagram (see Figure 6.2) and based on demand classification threshold values (see Table 6.3), analysers in the information fractals located in both manufacturer and suppliers' facilities classified the demand at different days between replenishment (*DBR*) from one day to five days and the results obtained from GURU are displayed in Table 6.16.

Table 6. 16: Demand class at different DBR (1day to 5days)

Fractal Name	**Part / Component**	**1 Day**	**2 Days**	**3 Days**	**4 Days**	**5 Days**
Packaging centre (A)	Part $_{AA}$	Smooth	Smooth	Smooth	Smooth	Smooth
Assembly centre (A)	Part $_{CA}$	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Low Variable	Slow-Low Variable
Cutting centre (A)	(a)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Cutting centre (A)	(c)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Cutting centre (A)	(e)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Packaging centre (B)	Part $_{BA}$	Smooth	Smooth	Smooth	Smooth	Smooth
Assembly centre (B)	(b)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Low Variable	Slow-Low Variable
Assembly centre (B)	(d)	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Low Variable	Slow-Low Variable
Packaging centre (C)	Part $_{DC}$	Smooth	Smooth	Smooth	Smooth	Smooth
Dyeing centre (C)	Part $_{AC}$	Smooth	Slow-Low Variable	Slow-Highly Variable	Slow-Low Variable	Slow-Low Variable
Assembly centre (C)	Part $_{CC}$	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Cutting centre (C)	(a)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Cutting centre (C)	(b)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Cutting centre (C)	(c)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Cutting centre (C)	(d)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Cutting centre (C)	(e)	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Venezuela's facility	(a)	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Senegal's facility)	(b)	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Portugal's facility	(c)	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
Japan's facility	(d)	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable
South Korea's facility	(e)	Smooth	Smooth	Slow-Highly Variable	Slow-Highly Variable	Slow-Highly Variable

6.2.2.2. Results analysis and optimisation of the Safety stock

Since demand was variable and lead time was constant resolvers in both information fractal centres and information fractal supplier’s facilities used equations (6.2) and (6.4) to calculate the required safety stock with a service level of 95 percent and re-order point during the demand of one-month test period, the outcome from GURU Software is shown in Table 6.17.

Table 6. 17: Safety stock optimisation at different DBR (1day to 5days)

Fractal Name	Part / Component	1 Day	2 Days	3 Days	4 Days	5 Days
Packaging centre (A) (SS, ROP)	Part $_{AA}$	(533, 800)	(533, 800)	(533, 800)	(533, 800)	(533,800)
Assembly centre (A) (SS, ROP)	Part $_{CA}$	(510, 756)	(721, 966)	(854, 1099)	(957, 1202)	(1033,1278)
Cutting centre (A) (SS, ROP)	(a)	(649, 894)	(747, 992)	(859, 1104)	(958, 1203)	(1033,1278)
Cutting centre (A) (SS, ROP)	(c)	(649, 894)	(747, 992)	(859, 1104)	(958, 1203)	(1033,1278)
Cutting centre (A) (SS, ROP)	(e)	(649, 894)	(747, 992)	(859, 1104)	(958, 1203)	(1033,1278)
Packaging centre (B) (SS, ROP)	Part $_{BA}$	(533, 800)	(533, 800)	(533, 800)	(533, 800)	(533,800)
Assembly centre (B) (SS, ROP)	(b)	(556, 824)	(786, 1053)	(931, 1198)	(1043, 1310)	(1126,1393)
Assembly centre (B) (SS, ROP)	(d)	(556, 824)	(786, 1053)	(931, 1198)	(1043, 1310)	(1126,1393)
Packaging centre (C) (SS, ROP)	Part $_{DC}$	(537, 809)	(537, 809)	(537, 809)	(537, 809)	(537, 809)
Dyeing centre (C) (SS, ROP)	Part $_{AC}$	(562, 833)	(794 , 1065)	(942, 1213)	(1056 ,1327)	(1139,1410)
Assembly centre (C) (SS, ROP)	Part $_{CC}$	(714, 985)	(822, 1093)	(947, 1218)	(1056,1327)	(1139,1410)
Cutting centre (C) (SS, ROP)	(a)	(738, 1009)	(863, 1134)	(969, 1240)	(1064,1335)	(1141,1412)
Cutting centre (C) (SS, ROP)	(b)	(738, 1009)	(863, 1134)	(969, 1240)	(1064,1335)	(1141,1412)
Cutting centre (C) (SS, ROP)	(c)	(738, 1009)	(863, 1134)	(969, 1240)	(1064,1335)	(1141,1412)
Cutting centre (C) (SS, ROP)	(d)	(738, 1009)	(863, 1134)	(969, 1240)	(1064,1335)	(1141,1412)
Cutting centre (C) (SS, ROP)	(e)	(738, 1009)	(863, 1134)	(969, 1240)	(1064,1335)	(1141,1412)
Venezuela's facility (SS, ROP)	(a)	(3971,15864)	(4741, 6634)	(5882,17774)	(6627,18519)	(7350,19242)
Senegal's facility) (SS, ROP)	(b)	(4242,17721)	(5019,18498)	(6265,19744)	(7122,20601)	(7932,21411)
Portugal's facility (SS, ROP)	(c)	(4222,17666)	(5041,18485)	(6227,19670)	(7015,20458)	(7778,21221)
Japan's facility (SS, ROP)	(d)	(4326,18344)	(5118,19137)	(6381,20399)	(7253,21271)	(8077,22095)
South Korea's facility (SS, ROP)	(e)	(4382,18859)	(5231,19709)	(6447,20924)	(7260,21737)	(8049,22526)

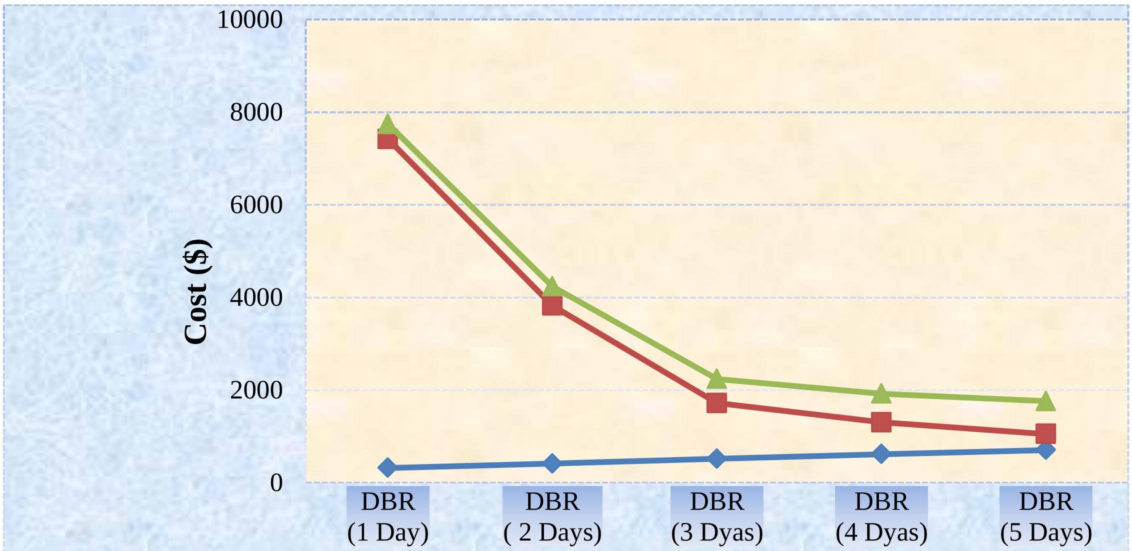
6.2.2.3 Results analysis and optimisation of Cycle stock

As part of cycle stock optimisation, the analyser in the information fractal VMI centre calculated replenishment cycle stock (*RCS*) and inventory holding costs (*IHC*) of cutting centres located in the production lines in the core manufacturer and also specified transportation cost from centralised VMI to core manufacturer using equations (6.11), (6.13) and 6.19 by investigating different days of replenishment from 1 day to 5 days.

To achieve the lowest total logistics cost from centralised VMI to core manufacturer, resolver used analyser's results to determine optimum replenishment cycle stock by integrating both the inventory holding costs and transportation costs with respect to different days of replenishment to choose the best match of inventory holding cost and transportation cost (see equation 6.20).

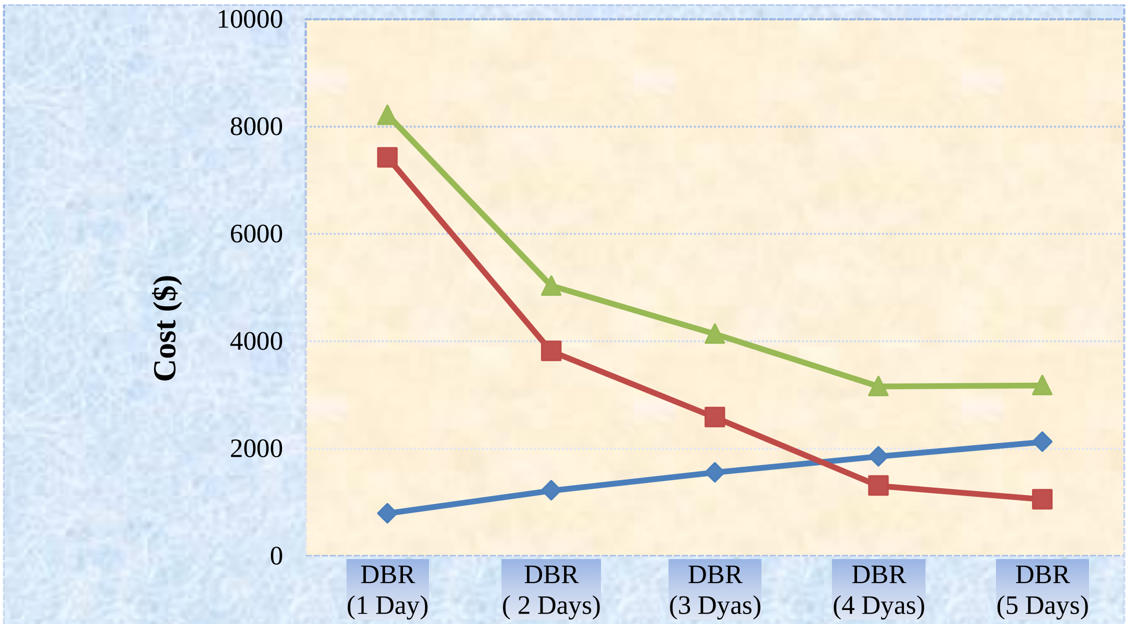
The results proved that during the demand of one-month test period for supplying components (a), (c) and (e) to Cutting centre (A), the lowest logistics cost can be achieved with a day between replenishment of five days (see Figure 6.12). While, for supplying components (b) and (d) to Cutting centre (B) with days between replenishment of four days (see Figure 6.13) and, finally, for supplying components (a), (b), (c), (d) and (e) to Cutting centre (C) with days between replenishment of four days as shown in Figure 6.14.

Thus, the optimum replenishment cycle stock (*RCS*) amount for shipping components to Cutting centre (A), (B) and (C) were 2094 components, 1206 components and 3055 components respectively.



	DBR (1 Day)	DBR (2 Days)	DBR (3 Dyas)	DBR (4 Dyas)	DBR (5 Days)
Inventory Holding Cost ($)	323	417	520	620	709
Transportation Cost ($)	7425	3826	1723	1308	1055
Total Logistics Cost ($)	7748	4243	2243	1928	1764

Figure 6. 12: Total logistics cost at different DBR (1 day to 5 days) from centralised VMI to Cutting centre (A)



	DBR (1 Day)	DBR (2 Days)	DBR (3 Dyas)	DBR (4 Dyas)	DBR (5 Days)
Inventory Holding Cost ($)	794	1219	1555	1855	2125
Transportation Cost ($)	7425	3816	2585	1308	1056
Total Logistics Cost ($)	8219	5035	4140	3163	3181

Figure 6. 13: Total logistics cost at different DBR (1 day to 5 days) from centralised VMI to Cutting centre (B)

	DBR (1 Day)	DBR (2 Days)	DBR (3 Dyas)	DBR (4 Dyas)	DBR (5 Days)
Inventory Holding Cost ($)	1367	1790	2189	2575	2936
Transportation Cost ($)	7425	2550	1800	1350	1050
Total Logistics Cost ($)	8792	4340	3989	3925	3986

Figure 6. 14: Total logistics cost at different DBR (1day to 5days) from centralised VMI to Cutting centre (C)

Since the replenishment cycle stock from centralised VMI to the manufacturer was optimised; the resolver, with respect to the optimal days between replenishment, selects the optimum number of shipment during the period, optimum shipment quantity and optimum types of transportation assets as detailed in the following points:

- Optimum numbers of shipment from centralised VMI to cutting centre (A) is seven shipments while for both cutting centre (B) and cutting centre (C) there are nine shipments during the demand of a one-month test period.
- Optimum quantity per shipping from centralised VMI to cutting centre (A), cutting centre (B) and cutting centre (C) are 3690, 2144 and 5420 components.
- Since the optimum quantity per shipping to cutting centres was more than 2000 components per shipment, Full Truck Load (TL) is assigned.

6.3. Conclusions

In this chapter, two new frameworks of the information fractal structure were separately proposed to manage and optimise inventory and logistics cost throughout the supply network and facilitate communication and collaboration between centralised Vendor-Managed-Inventory (VMI) and Just-In-Time production. Both proposed frameworks were applied in a hypothetical supply network using mathematical modelling and Supply Chain GURU Simulation Software and the results have been analysed using statistical techniques (MANOVA).

Application of the first proposed framework has introduced inventory control system which was a combination of both centralised and decentralised inventory control strategies and has led to increasing both collaboration and integration through the supply network.

Application of the second proposed framework has introduced a unique inventory control system based on JIT inventory concept and has led to an increase in both collaboration and integration throughout the supply network.

Moreover, this chapter provides a systematic method through which practitioners are able to decide upon the demand analysis, optimisation of both safety and cycle stock, select the optimum number of shipments, the shipment quantity and the types of transportation assets and, most importantly, achieve the lowest logistics cost.

Chapter Seven - Conclusions, contributions to knowledge, limitation and future work

In this research, a review of the conducted research is presented and discussed in the first section. In addition, the research contributions to knowledge and the limitations are provided. The chapter ends with some recommendations for the future work.

7.1. Review of conducted research

In this research, a framework for configuring/reconfiguring fractal supply network and logistics capabilities was developed. Configuration/reconfiguration was started by developing conceptual models based on the changes in the environments with respect to fractal supply network capabilities as self-similarity, self-organisation, self-optimisation, goal-orientation and dynamics. The scope of configuration/reconfiguration covered both optimisation and measurement.

As part of the measurement, the conceptual model of logistics capabilities and their composition in fractal supply network was proposed with three levels. The top level contained "*fractal supply network members*" (e.g. Supplier, Supplier Hub, Manufacturer, Distribution centre and Retailer). The middle level contained "*logistics capability criteria"* and includes Integration, Supply-oriented capability, Demand-oriented capability, Information exchange capability, and Time management and logistics cost capability. The bottom level contained "*logistics capability key elements*" related to each main criterion. Multi-Criteria Decision-Making (MCDM) methods were used to specify high-priority logistics capabilities within the fractal supply network. The relative importance of the measurement criteria was also assessed using analytical hierarchy process (AHP) and Fuzzy-AHP and the results were compared determining there was a slight difference between classical AHP prioritisation ratio and fuzzy AHP ratio. Moreover, the Expert Choice software was applied to dynamically change the priorities of the main criteria to determine how these changes affect the priorities of the lower sub-criteria. The result proved that "*Customer service focus*", "*Responsiveness to customer demand fluctuations*, and "*Use a fractal paradigm in information systems development*" received the highest ranking through the prioritisation of logistics capabilities within fractal supply network. Thus, as part of further investment planning, in this study, the development of information systems based on "*fractal paradigm*" was taken into consideration.

Subsequently, frameworks of the information fractal structures for optimising the selected problems, including distribution network sustainability, supply network inventory and communication and collaboration in supply network, were developed and are briefly outlined in the following bullets respectively:

- A new framework for the information fractal structure with two levels namely "*Information Fractal- Reconfiguration Centre*" as the top level "*Information Fractal- Distribution Centre* as the bottom level was proposed to optimise sustainability of distribution network dynamically through two variables; Greenfield service constraints and the minimum weight of shipments on board. Fractal in the top-level traced, observed and analysed distribution network sustainability status and determined the optimum reconfiguration solution and shared with fractals in the bottom level. Based on this information, fractals in the bottom level implement the reconfiguration orders and apply green vehicle route optimisation and then transmit sustainability performance information to the top-level fractal.
- A new framework of the information fractal structure with two levels, namely, *information fractal-centre* as a top level and the *information fractal supplier's facilit*y, *information fractal-manufacturer*, *information fractal-distribution hub* and *information fractal-retailer* as a bottom level was proposed to manage and optimise inventory in the supply network. Fractals in the bottom level traced, observed and analysed its downstream fractal demand and determined optimum safety stock and inventory policy which were shared with the fractal information centre in the top-level fractal. Based on this information, the information fractal

chain centre of the top-level fractal achieved the lowest total logistics cost among fractals of the bottom-level fractal by integrating both inventory holding costs and transportation costs and determined and shared optimum cycle stock for each fractal.

- A new information fractal structure consists of "*information fractal-core manufacturer*" and "*information fractal-centralised VMI*" was proposed to facilitate communication and collaboration between centralised Vendor-Managed-Inventory (VMI) and Just-In-Time production to optimise inventory and logistics cost throughout the supply network. Fractals in the manufacture traced, observed and analysed destination fractal demand and determined optimum safety stock, reorders points, and inventory policy then shared this information with its source fractal. Information fractal VMI centre in the bottom level fractals traced core manufacturer demand and share it with supplier facilities as its sub fractal. Supplier facilities analysed manufacturer demand and determined optimum safety stock, reorders the points and inventory policy which can be shared with their main manufacturing plants and information fractal VMI centre. Moreover, information fractal VMI centre determined the optimum replenishment cycle stock by integrating both inventory holding costs in the core manufacturer and transportation costs from centralised VMI to core manufacturer to achieve the lowest logistics cost by investigating the days between replenishment and scheduled optimum delivery frequency to the core manufacturer.

In terms of optimisation, with respect to the above conceptual models; mathematical and simulation models regarding the problems were developed and tested hypothetically and verified and validated using simulation tools as well as experimental factorial design and statistical techniques were used to generate and analyse the results which are briefly presented as follows:

- The proposed framework of an Information Fractal Structure for distribution network sustainability was applied to the hypothetical distribution network. Supply Chain GURU Software is adapted to implement the Greenfield analysis to identify the optimal number and location for setting up the new facilities. The new green vehicle route problem with split delivery was developed and implemented using simulated annealing algorithm which was programmed in MATLAB software. In terms of model verification and validation, the calculation was done without/with the minimum weight of shipments on board and the results were compared.
- Both of the proposed frameworks of an Information Fractal Structure for optimising supply network inventory and logistics cost, and an Information Fractal Structure for facilitating communication and collaboration between centralised VMI and JIT production were separately applied in the hypothetical supply networks using mathematical modelling and Supply Chain GURU Simulation Software for verification and validation purposes and the results have been analysed using statistical techniques (MANOVA).

7.2. Contributions to knowledge

The following bullet points presented here are the key achievements of this study.

- A framework for configuring fractal supply network for logistics capabilities in order to design, plan, implement and control supply network.
- A systematic approach that enables practitioners to measure and optimise the logistics capabilities within the fractal supply network.

- A methodology through which practitioners should be able to decide upon the different logistics capability factors, sub-factors and key elements to test, assess and improve enterprise's logistics capability.
- A unique dynamic sustainability control system for distribution network which has led to an increase in both collaboration and integration through the distribution network and an improvement in the process of sharing information across the network, which has proven to be a problematic area for industrialists.
- A systematic method through which practitioners should be able to decide upon the optimal number and location of distribution facilities as well as optimal types of fleet to minimise the CO_2 emission and transportation cost, maximise responsiveness and determine the optimal number of required transportation asset to meet customers demand through the distribution chain.
- A new green vehicle route problem with split delivery (GSDVRP) which led to a reduction in both CO_2 emission and transportation distance.
- A unique inventory control system, which is a combination of both centralised and decentralised inventory control strategies, which has led to an increase in both collaboration and integration through the supply network and to an improvement of the process of sharing information across the network.
- An easy method through which practitioners are able to decide upon the demand analysis and optimisation of both safety and cycle stock. In addition, to decide upon logistics cost at different replenishment frequencies.
- A new collaboration protocol between centralised VMI and JIT core manufacturer. Hence, allowing centralised VMI to select the optimum number of shipments, shipment quantity and types of transportation assets and, most importantly, achieving the lowest logistics cost.

7.3. Limitations

The developed methodologies and proposed frameworks were implemented and experimented using hypothetical cases. Thus, the results of this study should be viewed with this limitation in mind. Moreover, several assumptions were made during the implementation and experimentation of the methodologies. In addition, the implementation of the proposed producers in a real supply network would require significant investment. Hence, it can be recognised that the primary achievement of this work is the provision of new ideas for future development in the academic space.

7.4. Future works

In the course of the research project, it became apparent that there is very little research carried out in the areas of this study. Therefore, many of the new approaches are still fairly abstract concepts and there are several areas for future research within the scope of this research. Some of the most significant topics are discussed below.

- Information fractal structure should consist of five functions namely; observer, analyser, resolver, organizer and reporter, this work focused only on the analyser, organiser and resolver functions, it would be very beneficial to expand the proposed framework to include the other two functions in order to be a representative of a complete “Information Fractal”.
- There are three typical type of service levels often used in industry which are: the probability of not stocking out, fill rate and ready rate. In this research, only the first type was considered within the resolver function and considering the other two types could be scheduled for future work.
- There are three models to calculate safety stock and re-order point that may happen during the demand period. That demand is variable and lead time is constant, lead time is variable and demand is constant and both lead time and

demand are variable. In this research, only the first model was considered within the resolver function and considering the other two models could be scheduled for future work.

- In this research, a Pollution-Routing Problem (PRP) with a homogeneous fleet without considering the limited number of vehicles was investigated. In relation to future work, time window, vehicles number and vehicles constraints with heterogeneous vehicles should also be considered.
- Customer service focus, responsiveness to customer demand fluctuations, and use of a fractal paradigm in information systems development received the highest ranking through logistics capabilities prioritisation within fractal supply network. This work focused on the development of information systems based on the fractal paradigm. It would be very beneficial to consider the other two capabilities for future study.

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Appendix 1- Proposed questionnaire for measurement of logistics capabilities in fractal supply network

Introduction

As an important goal of our research to develop a framework for measuring the logistics capabilities in the fractal supply network, an Analytic Hierarchy Process (AHP) model is proposed in which the criteria and sub-criteria contributing to achieving this goal have been identified as shown in Figure 1.

The fractal supply network is a kind of reconfigured supply chain in order to provide a high level of adaptability to cope with today's market dynamic nature. Fractal supply network is now attracting many of industrialists due to its capabilities in terms of self-similarity, self-organizing, self-optimizing, goal orientation and dynamic nature of this type of supply chain. Each fractal has its own structure but with the same inputs and outputs, the ability to choose and use appropriate methods to optimise itself and divide large problems into small ones, and perform a goal-formation process to generate their own goals by coordinating processes with the participating fractals, modifying goals if necessary. Finally, each fractal has the ability to adapt to the dynamically changing environment.

This questionnaire is developed to gather the opinion of the practitioners, researchers and industrialists, to carry out a pairwise comparison between the criteria and sub-criteria within the proposed model based on fractal supply network. In addition, there is an opportunity at the end of the questionnaire to explore your opinion about whether other criteria or sub-criteria are missing and should be added. Your contribution and participation are highly appreciated and we would like to thank you in advance for your time and answers.

Level of education

…………………………………

1. **Level of occupation**

…………………………………

2. **Job Title**

…………………………………

3. **Logistics work experience (Year)**

…………………………………

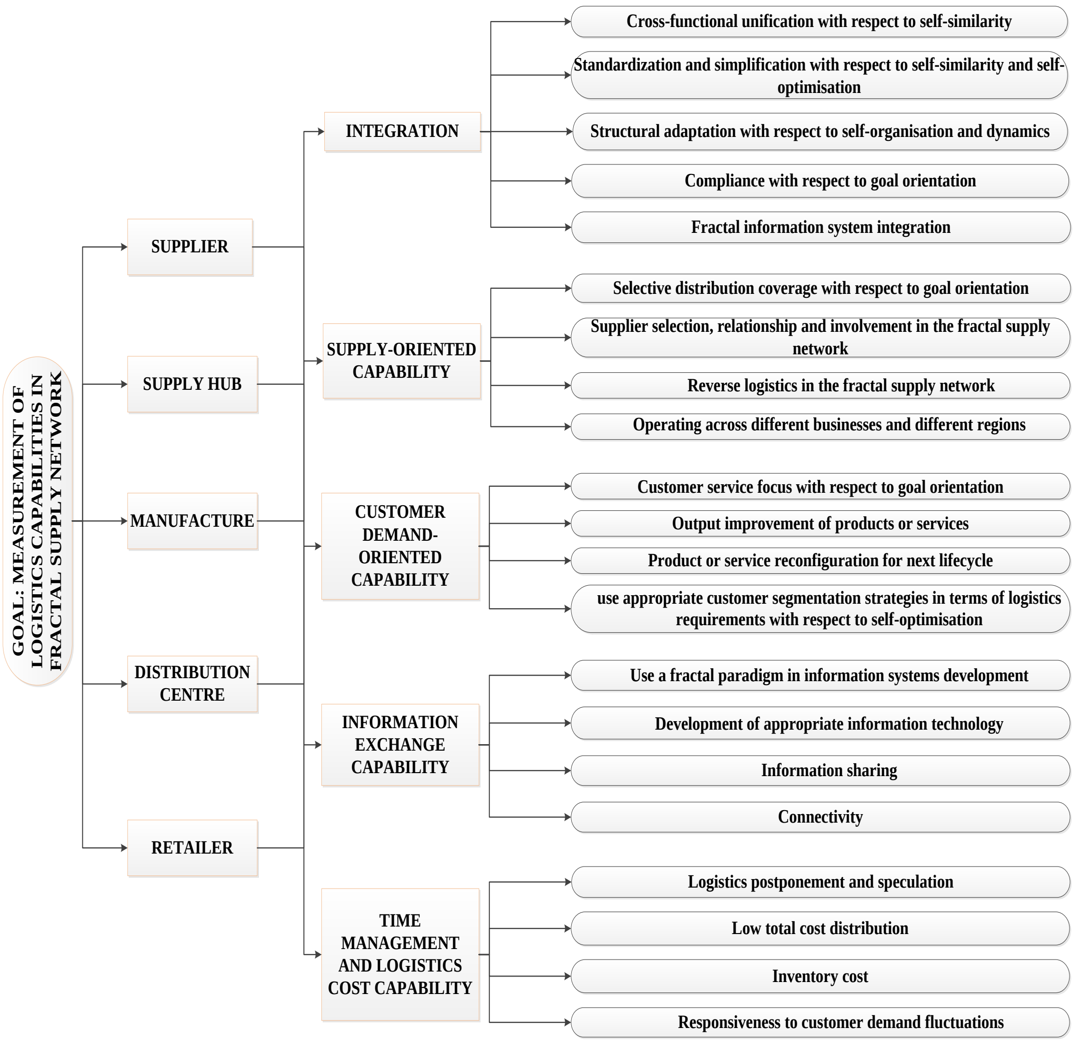

Figure 1: AHP model of fractal supply network logistics capabilities measurement

SECTION A

Proposed attributes and carry out a pairwise comparison between these attributes and the weight of each criterion and sub-criterions in fractal supply network.

4. **Compare the relative importance between Supplier and Supply Hub with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".**
   Mark only one oval.
   - 9 Supplier is extremely more important than Supply Hub
   - 7 Supplier is very strongly more important than Supply Hub
   - 5 Supplier is strongly more important than Supply Hub
   - 3 Supplier is moderately more important than Supply Hub
   - 1 Supplier and Supply Hub are equally important
   - 3 Supply Hub is moderately more important than Supplier
   - 5 Supply Hub is strongly more important than Supplier
   - 7 Supply Hub is very strongly more important than Supplier
   - 9 Supply Hub is extremely more important than Supplier

5. **Compare the relative importance between Supplier and Manufacture with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".**
   Mark only one oval.
   - 9 Supplier is extremely more important than Manufacture
   - 7 Supplier is very strongly more important than Manufacture
   - 5 Supplier is strongly more important than Manufacture
   - 3 Supplier is moderately more important than Manufacture
   - 1 Supplier and Manufacture are equally important
   - 3 Manufacture is moderately more important than Supplier
   - 5 Manufacture is strongly more important than Supplier
   - 7 Manufacture is very strongly more important than Supplier
   - 9 Manufacture is extremely more important than Supplier

6. **Compare the relative importance between Supplier and Distribution centre with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".**
   Mark only one oval.
   - 9 Supplier is extremely more important than Distribution centre
   - 7 Supplier is very strongly more important than Distribution centre
   - 5 Supplier is strongly more important than Distribution centre
   - 3 Supplier is moderately more important than Distribution centre
   - 1 Supplier and Distribution centre are equally important
   - 3 Distribution centre is moderately more important than Supplier
   - 5 Distribution centre is strongly more important than Supplier
   - 7 Distribution centre is very strongly more important than Supplier
   - 9 Distribution centre is extremely more important than Supplier

7. **Compare the relative importance between Supplier and Retailer with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".**
   Mark only one oval.
   - 9 Supplier is extremely more important than Retailer
   - 7 Supplier is very strongly more important than Retailer
   - 5 Supplier is strongly more important than Retailer
   - 3 Supplier is moderately more important than Retailer
   - 1 Supplier and Retailer are equally important
   - 3 Retailer is moderately more important than Supplier
   - 5 Retailer is strongly more important than Supplier
   - 7 Retailer is very strongly more important than Supplier
   - 9 Retailer is extremely more important than Supplier

8. **Compare the relative importance between Supply Hub and Manufacture with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".**
   Mark only one oval.
   - 9 Supply Hub is extremely more important than Manufacture
   - 7 Supply Hub is very strongly more important than Manufacture
   - 5 Supply Hub is strongly more important than Manufacture
   - 3 Supply Hub is moderately more important than Manufacture
   - 1 Supply Hub and Manufacture are equally important
   - 3 Manufacture is moderately more important than Supply Hub
   - 5 Manufacture is strongly more important than Supply Hub
   - 7 Manufacture is very strongly more important than Supply Hub
   - 9 Manufacture is extremely more important than Supply Hub

9. **Compare the relative importance between Supply Hub and Distribution centre with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".**
   Mark only one oval.
   - 9 Supply Hub is extremely more important than Distribution centre
   - 7 Supply Hub is very strongly more important than Distribution centre
   - 5 Supply Hub is strongly more important than Distribution centre
   - 3 Supply Hub is moderately more important than Distribution centre
   - 1 Supply Hub and Distribution centre are equally important
   - 3 Distribution centre is moderately more important than Supply Hub
   - 5 Distribution centre is strongly more important than Supply Hub
   - 7 Distribution centre is very strongly more important than Supply Hub
   - 9 Distribution centre is extremely more important than Supply Hub

10. **Compare the relative importance between Supply Hub and Retailer with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".**
   Mark only one oval.
   - 9 Supply Hub is extremely more important than Retailer
   - 7 Supply Hub is very strongly more important than Retailer
   - 5 Supply Hub is strongly more important than Retailer
   - 3 Supply Hub is moderately more important than Retailer
   - 1 Supply Hub and Retailer are equally important
   - 3 Retailer is moderately more important than Supply Hub
   - 5 Retailer is strongly more important than Supply Hub
   - 7 Retailer is very strongly more important than Supply Hub
   - 9 Retailer is extremely more important than Supply Hub

11. Compare the relative importance between Manufacture and Distribution centre with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".

Mark only one oval.

- 9 Manufacture is extremely more important than Distribution centre
- 7 Manufacture is very strongly more important than Distribution centre
- 5 Manufacture is strongly more important than Distribution centre
- 3 Manufacture is moderately more important than Distribution centre
- 1 Manufacture and Distribution centre are equally important
- 3 Distribution centre is moderately more important than Manufacture
- 5 Distribution centre is strongly more important than Manufacture
- 7 Distribution centre is very strongly more important than Manufacture
- 9 Distribution centre is extremely more important than Manufacture

12. Compare the relative importance between Manufacture and Retailer with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".

Mark only one oval

- 9 Manufacture is extremely more important than Retailer
- 7 Manufacture is very strongly more important than Retailer
- 5 Manufacture is strongly more important than Retailer
- 3 Manufacture is moderately more important than Retailer
- 1 Manufacture and Retailer are equally important
- 3 Retailer is moderately more important than Manufacture
- 5 Retailer is strongly more important than Manufacture
- 7 Retailer is very strongly more important than Manufacture
- 9 Retailer is extremely more important than Manufacture

13. Compare the relative importance between Distribution centre and Retailer with respect to the main goal which is creating "A Fractal supply network logistics capability measurement".

Mark only one oval.

- 9 Distribution centre is extremely more important than Retailer
- 7 Distribution centre is very strongly more important than Retailer
- 5 Distribution centre is strongly more important than Retailer
- 3 Distribution centre is moderately more important than Retailer
- 1 Distribution centre and Retailer are equally important
- 3 Retailer is moderately more important than Distribution centre
- 5 Retailer is strongly more important than Distribution centre
- 7 Retailer is very strongly more important than Distribution centre
- 9 Retailer is extremely more important than Distribution centre

14. Compare the relative importance between Integration and Supply-oriented capability with respect to "Supplier".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Supply-oriented capability** focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage.

Mark only one oval.

- 9 Integration is extremely more important than Supply-oriented capability
- 7 Integration is very strongly more important than Supply-oriented capability
- 5 Integration is strongly more important than Supply-oriented capability
- 3 Integration is moderately more important than Supply-oriented capability
- 1 Integration and Supply-oriented capability are equally important
- 3 Supply-oriented capability is moderately more important than Integration
- 5 Supply-oriented capability is strongly more important than Integration
- 7 Supply-oriented capability is very strongly more important than Integration
- 9 Supply-oriented capability is extremely more important than Integration

15. Compare the relative importance between Integration and Customer demand-oriented capability with respect to the "Supplier".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Integration is extremely more important than Customer demand-oriented capability
- 7 Integration is very strongly more important than Customer demand-oriented capability
- 5 Integration is strongly more important than Customer demand-oriented capability
- 3 Integration is moderately more important than Customer demand-oriented capability
- 1 Integration and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Integration
- 5 Customer demand-oriented capability is strongly more important than Integration
- 7 Customer demand-oriented capability is very strongly more important than Integration
- 9 Customer demand-oriented capability is extremely more important than Integration

16. Compare the relative importance between Integration and Information exchange capability with respect to the "Supplier".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Integration is extremely more important than Information exchange capability
- 7 Integration is very strongly more important than Information exchange capability
- 5 Integration is strongly more important than Information exchange capability
- 3 Integration is moderately more important than Information exchange capability
- 1 Integration and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than integration
- 5 Information exchange capability is strongly more important than Integration
- 7 Information exchange capability is very strongly more important than Integration
- 9 Information exchange capability is extremely more important than Integration

17. Compare the relative importance between Integration and Time management and logistics cost capability with respect to the "Supplier".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Integration is extremely more important than Time management and logistics cost capability
- 7 Integration is very strongly more important than Time management and logistics cost capability
- 5 Integration is strongly more important than Time management and logistics cost capability
- 3 Integration is moderately more important than Time management and logistics cost capability
- 1 Integration and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Integration
- 5Time management and logistics cost capability is strongly more important than Integration
- 7Time management and logistics cost capability is very strongly more important than Integration
- 9 Time management and logistics cost capability is extremely more important than Integration

18. Compare the relative importance between Supply-oriented capability and Customer demand-oriented capability with respect to "Supplier".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Customer demand-oriented capability
- 7 Supply-oriented capability is very strongly more important than Customer demand-oriented capability
- 5 Supply-oriented capability is strongly more important than Customer demand-oriented capability
- 3 Supply-oriented capability is moderately more important than Customer demand-oriented capability
- 1 Supply-oriented capability and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Supply-oriented capability
- 5 Customer demand-oriented capability is strongly more important than Supply-oriented capability
- 7Customer demand-oriented capability is very strongly more important than Supply-oriented capability
- 9 Customer demand-oriented capability is extremely more important than Supply-oriented capability

19. **Compare the relative importance between Supply-oriented capability and Information exchange capability with respect to the "Supplier".**

    Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

    Mark only one oval.

    - 9 Supply-oriented capability is extremely more important than Information exchange capability
    - 7 Supply-oriented capability is very strongly more important than Information exchange capability
    - 5 Supply-oriented capability is strongly more important than Information exchange capability
    - 3 Supply-oriented capability is moderately more important than Information exchange capability
    - 1 Supply-oriented capability and Information exchange capability are equally important
    - 3 Information exchange capability is moderately more important than supply-oriented capability
    - 5 Information exchange capability is strongly more important than Supply-oriented capability
    - 7 Information exchange capability is very strongly more important than Supply-oriented capability
    - 9 Information exchange capability is extremely more important than Supply-oriented capability

20. **Compare the relative importance between Supply-oriented capability and Time management and logistics cost capability with respect to the "Supplier".**

    Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

    Mark only one oval.

    - 9 Supply-oriented capability is extremely more important than Time management and logistics cost capability
    - 7 Supply-oriented capability is very strongly more important than Time management and logistics cost capability
    - 5 Supply-oriented capability is strongly more important than Time management and logistics cost capability
    - 3 Supply-oriented capability is moderately more important than Time management and logistics cost capability
    - 1 Supply-oriented capability and Time management and logistics cost capability are equally important
    - 3 Time management and logistics cost capability is moderately more important than Supply-oriented capability
    - 5 Time management and logistics cost capability is strongly more important than Supply-oriented capability
    - 7 Time management and logistics cost capability is very strongly more important than Supply-oriented capability
    - 9 Time management and logistics cost capability is extremely more important than Supply-oriented capability

21. Compare the relative importance between Customer demand-oriented capability and Information exchange capability with respect to the "Supplier".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Information exchange capability
- 7 Customer demand-oriented capability is very strongly more important than Information exchange capability
- 5 Customer demand-oriented capability is strongly more important than Information exchange capability
- 3 Customer demand-oriented capability is moderately more important than Information exchange capability
- 1 Customer demand-oriented capability and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than Customer demand-oriented capability
- 5 Information exchange capability is strongly more important than Customer demand-oriented capability
- 7 Information exchange capability is very strongly more important than Customer demand-oriented capability
- 9 Information exchange capability is extremely more important than Customer demand-oriented capability

22. Compare the relative importance between Customer demand-oriented capability and Time management and logistics cost capability with respect to the "Supplier".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Time management and logistics cost capability
- 7 Customer demand-oriented capability is very strongly more important than Time management and logistics cost capability
- 5 Customer demand-oriented capability is strongly more important than Time management and logistics cost capability
- 3 Customer demand-oriented capability is moderately more important than Time management and logistics cost capability
- 1 Customer demand-oriented capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Customer demand-oriented capability
- 5 Time management and logistics cost capability is strongly more important than Customer demand-oriented capability
- 7 Time management and logistics cost capability is very strongly more important than Customer demand-oriented capability
- 9 Time management and logistics cost capability is extremely more important than Customer demand-oriented capability

23. Compare the relative importance between Information exchange capability and Time management and logistics cost capability with respect to the "Supplier".

Information exchange capability means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Information exchange capability is extremely more important than Time management and logistics cost capability
- 7 Information exchange capability is very strongly more important than Time management and logistics cost capability
- 5 Information exchange capability is strongly more important than Time management and logistics cost capability
- 3 Information exchange capability is moderately more important than Time management and logistics cost capability
- 1 Information exchange capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Information exchange capability
- 5 Time management and logistics cost capability is strongly more important than Information exchange capability
- 7 Time management and logistics cost capability is very strongly more important than Information exchange capability
- 9 Time management and logistics cost capability is extremely more important than Information exchange capability

24. Compare the relative importance between Integration and Supply-oriented capability with respect to "Supply Hub".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Supply-oriented capability** focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage.

Mark only one oval.

- 9 Integration is extremely more important than Supply-oriented capability
- 7 Integration is very strongly more important than Supply-oriented capability
- 5 Integration is strongly more important than Supply-oriented capability
- 3 Integration is moderately more important than Supply-oriented capability
- 1 Integration and Supply-oriented capability are equally important
- 3 Supply-oriented capability is moderately more important than Integration
- 5 Supply-oriented capability is strongly more important than Integration
- 7 Supply-oriented capability is very strongly more important than Integration
- 9 Supply-oriented capability is extremely more important than Integration

25. Compare the relative importance between Integration and Customer demand-oriented capability with respect to the "Supply Hub".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Integration is extremely more important than Customer demand-oriented capability
- 7 Integration is very strongly more important than Customer demand-oriented capability
- 5 Integration is strongly more important than Customer demand-oriented capability
- 3 Integration is moderately more important than Customer demand-oriented capability
- 1 Integration and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Integration
- 5 Customer demand-oriented capability is strongly more important than Integration
- 7 Customer demand-oriented capability is very strongly more important than Integration
- 9 Customer demand-oriented capability is extremely more important than Integration

26. Compare the relative importance between Integration and Information exchange capability with respect to the "Supply Hub".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Integration is extremely more important than Information exchange capability
- 7 Integration is very strongly more important than Information exchange capability
- 5 Integration is strongly more important than Information exchange capability
- 3 Integration is moderately more important than Information exchange capability
- 1 Integration and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than integration
- 5 Information exchange capability is strongly more important than Integration
- 7 Information exchange capability is very strongly more important than Integration
- 9 Information exchange capability is extremely more important than Integration

27. Compare the relative importance between Integration and Time management and logistics cost capability with respect to the "Supply Hub".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Integration is extremely more important than Time management and logistics cost capability
- 7 Integration is very strongly more important than Time management and logistics cost capability
- 5 Integration is strongly more important than Time management and logistics cost capability
- 3 Integration is moderately more important than Time management and logistics cost capability
- 1 Integration and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Integration
- 5Time management and logistics cost capability is strongly more important than Integration
- 7Time management and logistics cost capability is very strongly more important than Integration
- 9 Time management and logistics cost capability is extremely more important than Integration

28. Compare the relative importance between Supply-oriented capability and Customer demand-oriented capability with respect to "Supply Hub".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Customer demand-oriented capability
- 7 Supply-oriented capability is very strongly more important than Customer demand-oriented capability
- 5 Supply-oriented capability is strongly more important than Customer demand-oriented capability
- 3 Supply-oriented capability is moderately more important than Customer demand-oriented capability
- 1 Supply-oriented capability and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Supply-oriented capability
- 5 Customer demand-oriented capability is strongly more important than Supply-oriented capability
- 7Customer demand-oriented capability is very strongly more important than Supply-oriented capability
- 9 Customer demand-oriented capability is extremely more important than Supply-oriented capability

29. Compare the relative importance between Supply-oriented capability and Information exchange capability with respect to the "Supply Hub".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Information exchange capability
- 7 Supply-oriented capability is very strongly more important than Information exchange capability
- 5 Supply-oriented capability is strongly more important than Information exchange capability
- 3 Supply-oriented capability is moderately more important than Information exchange capability
- 1 Supply-oriented capability and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than supply-oriented capability
- 5 Information exchange capability is strongly more important than Supply-oriented capability
- 7 Information exchange capability is very strongly more important than Supply-oriented capability
- 9 Information exchange capability is extremely more important than Supply-oriented capability

30. Compare the relative importance between Supply-oriented capability and Time management and logistics cost capability with respect to the "Supply Hub".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Time management and logistics cost capability
- 7 Supply-oriented capability is very strongly more important than Time management and logistics cost capability
- 5 Supply-oriented capability is strongly more important than Time management and logistics cost capability
- 3 Supply-oriented capability is moderately more important than Time management and logistics cost capability
- 1 Supply-oriented capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Supply-oriented capability
- 5 Time management and logistics cost capability is strongly more important than Supply-oriented capability
- 7 Time management and logistics cost capability is very strongly more important than Supply-oriented capability
- 9 Time management and logistics cost capability is extremely more important than Supply-oriented capability

31. Compare the relative importance between Customer demand-oriented capability and Information exchange capability with respect to the "Supply Hub".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Information exchange capability
- 7 Customer demand-oriented capability is very strongly more important than Information exchange capability
- 5 Customer demand-oriented capability is strongly more important than Information exchange capability
- 3 Customer demand-oriented capability is moderately more important than Information exchange capability
- 1 Customer demand-oriented capability and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than Customer demand-oriented capability
- 5 Information exchange capability is strongly more important than Customer demand-oriented capability
- 7 Information exchange capability is very strongly more important than Customer demand-oriented capability
- 9 Information exchange capability is extremely more important than Customer demand-oriented capability

32. Compare the relative importance between Customer demand-oriented capability and Time management and logistics cost capability with respect to the "Supply Hub".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Time management and logistics cost capability
- 7 Customer demand-oriented capability is very strongly more important than Time management and logistics cost capability
- 5 Customer demand-oriented capability is strongly more important than Time management and logistics cost capability
- 3 Customer demand-oriented capability is moderately more important than Time management and logistics cost capability
- 1 Customer demand-oriented capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Customer demand-oriented capability
- 5 Time management and logistics cost capability is strongly more important than Customer demand-oriented capability
- 7 Time management and logistics cost capability is very strongly more important than Customer demand-oriented capability
- 9 Time management and logistics cost capability is extremely more important than Customer demand-oriented capability

33. Compare the relative importance between Information exchange capability and Time management and logistics cost capability with respect to the "Supply Hub".

Information exchange capability means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Information exchange capability is extremely more important than Time management and logistics cost capability
- 7 Information exchange capability is very strongly more important than Time management and logistics cost capability
- 5 Information exchange capability is strongly more important than Time management and logistics cost capability
- 3 Information exchange capability is moderately more important than Time management and logistics cost capability
- 1 Information exchange capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Information exchange capability
- 5 Time management and logistics cost capability is strongly more important than Information exchange capability
- 7 Time management and logistics cost capability is very strongly more important than Information exchange capability
- 9 Time management and logistics cost capability is extremely more important than Information exchange capability

34. Compare the relative importance between Integration and Supply-oriented capability with respect to "Manufacture".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Supply-oriented capability** focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage.

Mark only one oval.

- 9 Integration is extremely more important than Supply-oriented capability
- 7 Integration is very strongly more important than Supply-oriented capability
- 5 Integration is strongly more important than Supply-oriented capability
- 3 Integration is moderately more important than Supply-oriented capability
- 1 Integration and Supply-oriented capability are equally important
- 3 Supply-oriented capability is moderately more important than Integration
- 5 Supply-oriented capability is strongly more important than Integration
- 7 Supply-oriented capability is very strongly more important than Integration
- 9 Supply-oriented capability is extremely more important than Integration

35. Compare the relative importance between Integration and Customer demand-oriented capability with respect to the "Manufacture".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Integration is extremely more important than Customer demand-oriented capability
- 7 Integration is very strongly more important than Customer demand-oriented capability
- 5 Integration is strongly more important than Customer demand-oriented capability
- 3 Integration is moderately more important than Customer demand-oriented capability
- 1 Integration and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Integration
- 5 Customer demand-oriented capability is strongly more important than Integration
- 7 Customer demand-oriented capability is very strongly more important than Integration
- 9 Customer demand-oriented capability is extremely more important than Integration

36. Compare the relative importance between Integration and Information exchange capability with respect to the "Manufacture".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Integration is extremely more important than Information exchange capability
- 7 Integration is very strongly more important than Information exchange capability
- 5 Integration is strongly more important than Information exchange capability
- 3 Integration is moderately more important than Information exchange capability
- 1 Integration and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than integration
- 5 Information exchange capability is strongly more important than Integration
- 7 Information exchange capability is very strongly more important than Integration
- 9 Information exchange capability is extremely more important than Integration

37. Compare the relative importance between Integration and Time management and logistics cost capability with respect to the "Manufacture".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Integration is extremely more important than Time management and logistics cost capability
- 7 Integration is very strongly more important than Time management and logistics cost capability
- 5 Integration is strongly more important than Time management and logistics cost capability
- 3 Integration is moderately more important than Time management and logistics cost capability
- 1 Integration and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Integration
- 5Time management and logistics cost capability is strongly more important than Integration
- 7Time management and logistics cost capability is very strongly more important than Integration
- 9 Time management and logistics cost capability is extremely more important than Integration

38. Compare the relative importance between Supply-oriented capability and Customer demand-oriented capability with respect to "Manufacture".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Customer demand-oriented capability
- 7 Supply-oriented capability is very strongly more important than Customer demand-oriented capability
- 5 Supply-oriented capability is strongly more important than Customer demand-oriented capability
- 3 Supply-oriented capability is moderately more important than Customer demand-oriented capability
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- 3 Customer demand-oriented capability is moderately more important than Supply-oriented capability
- 5 Customer demand-oriented capability is strongly more important than Supply-oriented capability
- 7Customer demand-oriented capability is very strongly more important than Supply-oriented capability
- 9 Customer demand-oriented capability is extremely more important than Supply-oriented capability

39. Compare the relative importance between Supply-oriented capability and Information exchange capability with respect to the "Manufacture".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Information exchange capability
- 7 Supply-oriented capability is very strongly more important than Information exchange capability
- 5 Supply-oriented capability is strongly more important than Information exchange capability
- 3 Supply-oriented capability is moderately more important than Information exchange capability
- 1 Supply-oriented capability and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than supply-oriented capability
- 5 Information exchange capability is strongly more important than Supply-oriented capability
- 7 Information exchange capability is very strongly more important than Supply-oriented capability
- 9 Information exchange capability is extremely more important than Supply-oriented capability

40. Compare the relative importance between Supply-oriented capability and Time management and logistics cost capability with respect to the "Manufacture".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Time management and logistics cost capability
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- 5 Supply-oriented capability is strongly more important than Time management and logistics cost capability
- 3 Supply-oriented capability is moderately more important than Time management and logistics cost capability
- 1 Supply-oriented capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Supply-oriented capability
- 5 Time management and logistics cost capability is strongly more important than Supply-oriented capability
- 7 Time management and logistics cost capability is very strongly more important than Supply-oriented capability
- 9 Time management and logistics cost capability is extremely more important than Supply-oriented capability

41. **Compare the relative importance between Customer demand-oriented capability and Information exchange capability with respect to the "Manufacture".**

    Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

    Mark only one oval.

    - 9 Customer demand-oriented capability is extremely more important than Information exchange capability
    - 7 Customer demand-oriented capability is very strongly more important than Information exchange capability
    - 5 Customer demand-oriented capability is strongly more important than Information exchange capability
    - 3 Customer demand-oriented capability is moderately more important than Information exchange capability
    - 1 Customer demand-oriented capability and Information exchange capability are equally important
    - 3 Information exchange capability is moderately more important than Customer demand-oriented capability
    - 5 Information exchange capability is strongly more important than Customer demand-oriented capability
    - 7 Information exchange capability is very strongly more important than Customer demand-oriented capability
    - 9 Information exchange capability is extremely more important than Customer demand-oriented capability

42. **Compare the relative importance between Customer demand-oriented capability and Time management and logistics cost capability with respect to the "Manufacture".**

    Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

    Mark only one oval.

    - 9 Customer demand-oriented capability is extremely more important than Time management and logistics cost capability
    - 7 Customer demand-oriented capability is very strongly more important than Time management and logistics cost capability
    - 5 Customer demand-oriented capability is strongly more important than Time management and logistics cost capability
    - 3 Customer demand-oriented capability is moderately more important than Time management and logistics cost capability
    - 1 Customer demand-oriented capability and Time management and logistics cost capability are equally important
    - 3 Time management and logistics cost capability is moderately more important than Customer demand-oriented capability
    - 5 Time management and logistics cost capability is strongly more important than Customer demand-oriented capability
    - 7 Time management and logistics cost capability is very strongly more important than Customer demand-oriented capability
    - 9 Time management and logistics cost capability is extremely more important than Customer demand-oriented capability

43. Compare the relative importance between Information exchange capability and Time management and logistics cost capability with respect to the "Manufacture".

Information exchange capability means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Information exchange capability is extremely more important than Time management and logistics cost capability
- 7 Information exchange capability is very strongly more important than Time management and logistics cost capability
- 5 Information exchange capability is strongly more important than Time management and logistics cost capability
- 3 Information exchange capability is moderately more important than Time management and logistics cost capability
- 1 Information exchange capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Information exchange capability
- 5 Time management and logistics cost capability is strongly more important than Information exchange capability
- 7 Time management and logistics cost capability is very strongly more important than Information exchange capability
- 9 Time management and logistics cost capability is extremely more important than Information exchange capability

44. Compare the relative importance between Integration and Supply-oriented capability with respect to "Distribution centre".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Supply-oriented capability** focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage.

Mark only one oval.

- 9 Integration is extremely more important than Supply-oriented capability
- 7 Integration is very strongly more important than Supply-oriented capability
- 5 Integration is strongly more important than Supply-oriented capability
- 3 Integration is moderately more important than Supply-oriented capability
- 1 Integration and Supply-oriented capability are equally important
- 3 Supply-oriented capability is moderately more important than Integration
- 5 Supply-oriented capability is strongly more important than Integration
- 7 Supply-oriented capability is very strongly more important than Integration
- 9 Supply-oriented capability is extremely more important than Integration

45. Compare the relative importance between Integration and Customer demand-oriented capability with respect to the "Distribution centre".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Integration is extremely more important than Customer demand-oriented capability
- 7 Integration is very strongly more important than Customer demand-oriented capability
- 5 Integration is strongly more important than Customer demand-oriented capability
- 3 Integration is moderately more important than Customer demand-oriented capability
- 1 Integration and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Integration
- 5 Customer demand-oriented capability is strongly more important than Integration
- 7 Customer demand-oriented capability is very strongly more important than Integration
- 9 Customer demand-oriented capability is extremely more important than Integration

46. Compare the relative importance between Integration and Information exchange capability with respect to the "Distribution centre".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Integration is extremely more important than Information exchange capability
- 7 Integration is very strongly more important than Information exchange capability
- 5 Integration is strongly more important than Information exchange capability
- 3 Integration is moderately more important than Information exchange capability
- 1 Integration and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than integration
- 5 Information exchange capability is strongly more important than Integration
- 7 Information exchange capability is very strongly more important than Integration
- 9 Information exchange capability is extremely more important than Integration

47. Compare the relative importance between Integration and Time management and logistics cost capability with respect to the "Distribution centre".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Integration is extremely more important than Time management and logistics cost capability
- 7 Integration is very strongly more important than Time management and logistics cost capability
- 5 Integration is strongly more important than Time management and logistics cost capability
- 3 Integration is moderately more important than Time management and logistics cost capability
- 1 Integration and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Integration
- 5Time management and logistics cost capability is strongly more important than Integration
- 7Time management and logistics cost capability is very strongly more important than Integration
- 9 Time management and logistics cost capability is extremely more important than Integration

48. Compare the relative importance between Supply-oriented capability and Customer demand-oriented capability with respect to "Distribution centre".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Customer demand-oriented capability
- 7 Supply-oriented capability is very strongly more important than Customer demand-oriented capability
- 5 Supply-oriented capability is strongly more important than Customer demand-oriented capability
- 3 Supply-oriented capability is moderately more important than Customer demand-oriented capability
- 1 Supply-oriented capability and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Supply-oriented capability
- 5 Customer demand-oriented capability is strongly more important than Supply-oriented capability
- 7Customer demand-oriented capability is very strongly more important than Supply-oriented capability
- 9 Customer demand-oriented capability is extremely more important than Supply-oriented capability

49. Compare the relative importance between Supply-oriented capability and Information exchange capability with respect to the "Distribution centre".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Information exchange capability
- 7 Supply-oriented capability is very strongly more important than Information exchange capability
- 5 Supply-oriented capability is strongly more important than Information exchange capability
- 3 Supply-oriented capability is moderately more important than Information exchange capability
- 1 Supply-oriented capability and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than supply-oriented capability
- 5 Information exchange capability is strongly more important than Supply-oriented capability
- 7 Information exchange capability is very strongly more important than Supply-oriented capability
- 9 Information exchange capability is extremely more important than Supply-oriented capability

50. Compare the relative importance between Supply-oriented capability and Time management and logistics cost capability with respect to the "Distribution centre".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Time management and logistics cost capability
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- 5 Time management and logistics cost capability is strongly more important than Supply-oriented capability
- 7 Time management and logistics cost capability is very strongly more important than Supply-oriented capability
- 9 Time management and logistics cost capability is extremely more important than Supply-oriented capability

51. Compare the relative importance between Customer demand-oriented capability and Information exchange capability with respect to the "Distribution centre".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Information exchange capability
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- 5 Customer demand-oriented capability is strongly more important than Information exchange capability
- 3 Customer demand-oriented capability is moderately more important than Information exchange capability
- 1 Customer demand-oriented capability and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than Customer demand-oriented capability
- 5 Information exchange capability is strongly more important than Customer demand-oriented capability
- 7 Information exchange capability is very strongly more important than Customer demand-oriented capability
- 9 Information exchange capability is extremely more important than Customer demand-oriented capability

52. Compare the relative importance between Customer demand-oriented capability and Time management and logistics cost capability with respect to the "Distribution centre".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Time management and logistics cost capability
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- 1 Customer demand-oriented capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Customer demand-oriented capability
- 5 Time management and logistics cost capability is strongly more important than Customer demand-oriented capability
- 7 Time management and logistics cost capability is very strongly more important than Customer demand-oriented capability
- 9 Time management and logistics cost capability is extremely more important than Customer demand-oriented capability

53. Compare the relative importance between Information exchange capability and Time management and logistics cost capability with respect to the "Distribution centre".

Information exchange capability means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Information exchange capability is extremely more important than Time management and logistics cost capability
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- 3 Information exchange capability is moderately more important than Time management and logistics cost capability
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- 5 Time management and logistics cost capability is strongly more important than Information exchange capability
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- 9 Time management and logistics cost capability is extremely more important than Information exchange capability

54. Compare the relative importance between Integration and Supply-oriented capability with respect to "Retailer".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Supply-oriented capability** focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage.

Mark only one oval.

- 9 Integration is extremely more important than Supply-oriented capability
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- 3 Supply-oriented capability is moderately more important than Integration
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- 7 Supply-oriented capability is very strongly more important than Integration
- 9 Supply-oriented capability is extremely more important than Integration

55. Compare the relative importance between Integration and Customer demand-oriented capability with respect to the "Retailer".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Integration is extremely more important than Customer demand-oriented capability
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- 9 Customer demand-oriented capability is extremely more important than Integration

56. Compare the relative importance between Integration and Information exchange capability with respect to the "Retailer".

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Integration is extremely more important than Information exchange capability
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- 1 Integration and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than integration
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- 9 Information exchange capability is extremely more important than Integration

57. **Compare the relative importance between Integration and Time management and logistics cost capability with respect to the "Retailer".**

Integration means a state that exists among internal organizational elements that are necessary to achieve unity of effort to meet organizational goals; includes internal and external components. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Integration is extremely more important than Time management and logistics cost capability
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- 5Time management and logistics cost capability is strongly more important than Integration
- 7Time management and logistics cost capability is very strongly more important than Integration
- 9 Time management and logistics cost capability is extremely more important than Integration

58. **Compare the relative importance between Supply-oriented capability and Customer demand-oriented capability with respect to "Retailer".**

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Customer demand-oriented capability** provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Customer demand-oriented capability
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- 5 Supply-oriented capability is strongly more important than Customer demand-oriented capability
- 3 Supply-oriented capability is moderately more important than Customer demand-oriented capability
- 1 Supply-oriented capability and Customer demand-oriented capability are equally important
- 3 Customer demand-oriented capability is moderately more important than Supply-oriented capability
- 5 Customer demand-oriented capability is strongly more important than Supply-oriented capability
- 7Customer demand-oriented capability is very strongly more important than Supply-oriented capability
- 9 Customer demand-oriented capability is extremely more important than Supply-oriented capability

59. Compare the relative importance between Supply-oriented capability and Information exchange capability with respect to the "Retailer".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Information exchange capability
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- 3 Supply-oriented capability is moderately more important than Information exchange capability
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- 3 Information exchange capability is moderately more important than supply-oriented capability
- 5 Information exchange capability is strongly more important than Supply-oriented capability
- 7 Information exchange capability is very strongly more important than Supply-oriented capability
- 9 Information exchange capability is extremely more important than Supply-oriented capability

60. Compare the relative importance between Supply-oriented capability and Time management and logistics cost capability with respect to the "Retailer".

Supply-oriented capability focuses on the internal customer's relationship in the supply network and also emphasizes distribution networks for market value and for competitive advantage. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Supply-oriented capability is extremely more important than Time management and logistics cost capability
- 7 Supply-oriented capability is very strongly more important than Time management and logistics cost capability
- 5 Supply-oriented capability is strongly more important than Time management and logistics cost capability
- 3 Supply-oriented capability is moderately more important than Time management and logistics cost capability
- 1 Supply-oriented capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Supply-oriented capability
- 5 Time management and logistics cost capability is strongly more important than Supply-oriented capability
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- 9 Time management and logistics cost capability is extremely more important than Supply-oriented capability

61. Compare the relative importance between Customer demand-oriented capability and Information exchange capability with respect to the "Retailer".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Information exchange capability** means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Information exchange capability
- 7 Customer demand-oriented capability is very strongly more important than Information exchange capability
- 5 Customer demand-oriented capability is strongly more important than Information exchange capability
- 3 Customer demand-oriented capability is moderately more important than Information exchange capability
- 1 Customer demand-oriented capability and Information exchange capability are equally important
- 3 Information exchange capability is moderately more important than Customer demand-oriented capability
- 5 Information exchange capability is strongly more important than Customer demand-oriented capability
- 7 Information exchange capability is very strongly more important than Customer demand-oriented capability
- 9 Information exchange capability is extremely more important than Customer demand-oriented capability

62. Compare the relative importance between Customer demand-oriented capability and Time management and logistics cost capability with respect to the "Retailer".

Customer demand-oriented capability provides product or service differentiation and service enhancement for continuous distinctiveness for customers by targeting a given customer base and meeting or exceeding their expectations by providing unique, value-added activities. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Customer demand-oriented capability is extremely more important than Time management and logistics cost capability
- 7 Customer demand-oriented capability is very strongly more important than Time management and logistics cost capability
- 5 Customer demand-oriented capability is strongly more important than Time management and logistics cost capability
- 3 Customer demand-oriented capability is moderately more important than Time management and logistics cost capability
- 1 Customer demand-oriented capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Customer demand-oriented capability
- 5 Time management and logistics cost capability is strongly more important than Customer demand-oriented capability
- 7 Time management and logistics cost capability is very strongly more important than Customer demand-oriented capability
- 9 Time management and logistics cost capability is extremely more important than Customer demand-oriented capability

63. Compare the relative importance between Information exchange capability and Time management and logistics cost capability with respect to the "Retailer".

Information exchange capability means the ability to acquires, analyses, stores, and distributes tactical and strategic information both inside and outside the firm that enables firm to gain a distinct competitive advantage in the marketplace. **Time management and logistics cost capability** means the effective management of time and cost to eliminate wasted capital, inventory and minimise logistics cost in the whole supply network.

Mark only one oval.

- 9 Information exchange capability is extremely more important than Time management and logistics cost capability
- 7 Information exchange capability is very strongly more important than Time management and logistics cost capability
- 5 Information exchange capability is strongly more important than Time management and logistics cost capability
- 3 Information exchange capability is moderately more important than Time management and logistics cost capability
- 1 Information exchange capability and Time management and logistics cost capability are equally important
- 3 Time management and logistics cost capability is moderately more important than Information exchange capability
- 5 Time management and logistics cost capability is strongly more important than Information exchange capability
- 7 Time management and logistics cost capability is very strongly more important than Information exchange capability
- 9 Time management and logistics cost capability is extremely more important than Information exchange capability

64. Compare the relative importance between Cross-functional unification with respect to self-similarity and Standardisation and simplification with respect to self-similarity and self-optimisation with respect to the "Integration".

Cross-functional unification means integration of cross-enterprise functionality into manageable operational processes among Basic Fractal Units (BFU) as well as fractals in the different levels. **Standardisation and simplification** mean establishment and identification of cross-functional policies of procedures and simplification of adaption and continuous improvement of best practices among Basic Fractal Units (BFU) as well as fractals in the different levels.

Mark only one oval.

- 9 Cross-functional unification with respect to self-similarity is extremely more important than Standardisation and simplification with respect to self-similarity and self-optimisation
- 7 Cross-functional unification with respect to self-similarity is very strongly more important than Standardisation and simplification with respect to self-similarity and self-optimisation
- 5 Cross-functional unification with respect to self-similarity is strongly more important than Standardisation and simplification with respect to self-similarity and self-optimisation
- 3 Cross-functional unification with respect to self-similarity is moderately more important than Standardisation and simplification with respect to self-similarity and self-optimisation
- 1 Cross-functional unification with respect to self-similarity and Standardization and simplification with respect to self-similarity and self-optimisation are equally important
- 3 Standardisation and simplification with respect to self-similarity and self-optimisation is moderately more important than Cross-functional unification with respect to self-similarity
- 5 Standardisation and simplification with respect to self-similarity and self-optimisation is strongly more important than Cross-functional unification with respect to self-similarity
- 7 Standardisation and simplification with respect to self-similarity and self-optimisation is very strongly more important than Cross-functional unification with respect to self-similarity
- 9 Standardisation and simplification with respect to self-similarity and self-optimisation is extremely more important than Cross-functional unification with respect to self-similarity

65. Compare the relative importance between Cross-functional unification with respect to self-similarity and Structural adaptation with respect to self-organisation and dynamics with respect to the "Integration".

Cross-functional unification means integration of cross-enterprise functionality into manageable operational processes among Basic Fractal Units (BFU) as well as fractals in the different levels. **Structural adaptation** means appropriate modification of network structure and deployment of physical assets to facilitate integration among Basic Fractal Units (BFU) as well as fractals in the different levels.

Mark only one oval.

- 9 Cross-functional unification with respect to self-similarity is extremely more important than Structural adaptation with respect to self-organisation and dynamics
- 7 Cross-functional unification with respect to self-similarity is very strongly more important than Structural adaptation with respect to self-organisation and dynamics
- 5 Cross-functional unification with respect to self-similarity is strongly more important than Structural adaptation with respect to self-organisation and dynamics
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- 3 Structural adaptation with respect to self-organisation and dynamics is moderately more important than Cross-functional unification with respect to self-similarity
- 5 Structural adaptation with respect to self-organisation and dynamics is strongly more important than Cross-functional unification with respect to self-similarity
- 7 Structural adaptation with respect to self-organisation and dynamics is very strongly more important than Cross-functional unification with respect to self-similarity
- 9 Structural adaptation with respect to self-organisation and dynamics is extremely more important than Cross-functional unification with respect to self-similarity

66. Compare the relative importance between Cross-functional unification with respect to self-similarity and Compliance with respect to goal orientation with respect to the "Integration".

Cross-functional unification means integration of cross-enterprise functionality into manageable operational processes among Basic Fractal Units (BFU) as well as fractals in the different levels. **Compliance** means adherence to established operational and administrative policies and procedures in the fractal supply network.

Mark only one oval.

- 9 Cross-functional unification with respect to self-similarity is extremely more important than Compliance with respect to goal orientation
- 7 Cross-functional unification with respect to self-similarity is very strongly more important than Compliance with respect to goal orientation
- 5 Cross-functional unification with respect to self-similarity is strongly more important than Compliance with respect to goal orientation
- 3 Cross-functional unification with respect to self-similarity is moderately more important than Compliance with respect to goal orientation
- 1 Cross-functional unification with respect to self-similarity and Compliance with respect to goal orientation are equally important
- 3 Compliance with respect to goal orientation is moderately more important than Cross-functional unification with respect to self-similarity
- 5 Compliance with respect to goal orientation is strongly more important than Cross-functional unification with respect to self-similarity
- 7 Compliance with respect to goal orientation is very strongly more important than Cross-functional unification with respect to self-similarity
- 9 Compliance with respect to goal orientation is extremely more important than Cross-functional unification with respect to self-similarity

67. Compare the relative importance between Cross-functional unification with respect to self-similarity and Fractal information system integration with respect to the "Integration"

Cross-functional unification means integration of cross-enterprise functionality into manageable operational processes among Basic Fractal Units (BFU) as well as fractals in the different levels. **Fractal information system integration** can be developed by fractal characteristics because each unit in fractal supply network has similar knowledge structure. Therefore, each unit has the ability to represent system procedures by using self-organization.

Mark only one oval.

- o 9 Cross-functional unification with respect to self-similarity is extremely more important than Fractal information system integration
- o 7 Cross-functional unification with respect to self-similarity unification is very strongly more important than Fractal information system integration
- o 5 Cross-functional unification with respect to self-similarity is strongly more important than Fractal information system integration
- o 3 Cross-functional unification with respect to self-similarity is moderately more important than Fractal information system integration
- o 1 Cross-functional unification with respect to self-similarity and Fractal information system integration are equally important
- o 3 Fractal information system integration is moderately more important than Cross-functional unification with respect to self-similarity
- o 5 Fractal information system integration is strongly more important than Cross-functional unification with respect to self-similarity
- o 7 Fractal information system integration is very strongly more important than Cross-functional unification with respect to self-similarity
- o 9 Fractal information system integration is extremely more important than Cross-functional unification with respect to self-similarity

68. Compare the relative importance between Standardisation and simplification with respect to self-similarity and Structural adaptation with respect to self-organisation and dynamics with respect to the "Integration".

Standardisation and simplification mean establishment and identification of cross-functional policies of procedures and simplification of adaption and continuous improvement of best practices among the Basic Fractal Units (BFU) as well as fractals in the different levels. **Structural adaptation** means appropriate modification of network structure and deployment of physical assets to facilitate integration among BFU as well as fractals in the different levels.

Mark only one oval.

- o 9 Standardisation and simplification with respect to self-similarity is extremely more important than Structural adaptation with respect to self-organisation and dynamics
- o 7 Standardisation and simplification with respect to self-similarity is very strongly more important than Structural adaptation with respect to self-organisation and dynamics
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- o 5 Structural adaptation with respect to self-organisation and dynamics is strongly more important than Standardisation and simplification with respect to self-similarity
- o 7 Structural adaptation with respect to self-organisation and dynamics is very strongly more important than Standardisation and simplification with respect to self-similarity
- o 9 Structural adaptation with respect to self-organisation and dynamics is extremely more important than Standardisation and simplification with respect to self-similarity

69. Compare the relative importance between Standardisation and simplification with respect to self-similarity and Compliance with respect to goal orientation with respect to the "Integration".

Standardisation and simplification mean establishment and identification of cross-functional policies of procedures and simplification of adaption and continuous improvement of best practices among the Basic Fractal Units (BFU) as well as fractals in the different levels. **Compliance** means adherence to established operational and administrative policies and procedures in the fractal supply network.

Mark only one oval.

- 9 Standardisation and simplification with respect to self-similarity is extremely more important than Compliance with respect to goal orientation
- 7 Standardisation and simplification with respect to self-similarity is very strongly more important than Compliance with respect to goal orientation
- 5 Standardisation and simplification with respect to self-similarity is strongly more important than Compliance with respect to goal orientation
- 3 Standardisation and simplification with respect to self-similarity is moderately more important than Compliance with respect to goal orientation
- 1 Standardisation and simplification with respect to self-similarity and Compliance with respect to goal orientation are equally important
- 3 Compliance with respect to goal orientation is moderately more important than Standardisation and simplification with respect to self-similarity
- 5 Compliance with respect to goal orientation is strongly more important than Standardisation and simplification with respect to self-similarity
- 7 Compliance with respect to goal orientation is very strongly more important than Standardisation and simplification with respect to self-similarity
- 9 Compliance with respect to goal orientation is extremely more important than Standardisation and simplification with respect to self-similarity

70. Compare the relative importance between Standardisation and simplification with respect to self-similarity and Fractal information system integration with respect to the "Integration".

Standardisation and simplification mean establishment and identification of cross-functional policies of procedures and simplification of adaption and continuous improvement of best practices among the Basic Fractal Units (BFU) as well as fractals in the different levels. **Fractal information system integration** can be developed by fractal characteristics because each unit in fractal supply network has similar knowledge structure. Therefore, each unit has the ability to represent system procedures by using self-organization.

Mark only one oval.

- 9 Standardisation and simplification with respect to self-similarity is extremely more important than fractal information system integration
- 7 Standardisation and simplification with respect to self-similarity is very strongly more important than Fractal information system integration
- 5 Standardisation and simplification with respect to self-similarity is strongly more important than Fractal information system integration
- 3 Standardisation and simplification with respect to self-similarity is moderately more important than Fractal information system integration
- 1 Standardisation and simplification with respect to self-similarity and Fractal information system integration are equally important
- 3 Fractal information system integration is moderately more important than Standardisation and simplification with respect to self-similarity
- 5 Fractal information system integration is strongly more important than Standardisation and simplification with respect to self-similarity
- 7 Fractal information system integration is very strongly more important than Standardisation and simplification with respect to self-similarity
- 9 Fractal information system integration is extremely more important than Standardisation and simplification with respect to self-similarity

71. Compare the relative importance between Structural adaptation with respect to self-organisation and dynamics and Compliance with respect to goal orientation with respect to the "Integration".

Structural adaptation means appropriate modification of network structure and deployment of physical assets to facilitate integration among Basic Fractal Units (BFU) as well as fractals in the different levels. **Compliance** means adherence to established operational and administrative policies and procedures in the fractal supply network.

Mark only one oval.

- 9 Structural adaptation with respect to self-organisation and dynamics is extremely more important than compliance
- 7 Structural adaptation with respect to self-organisation and dynamics is very strongly more important than Compliance with respect to goal orientation
- 5 Structural adaptation with respect to self-organisation and dynamics is strongly more important than Compliance with respect to goal orientation
- 3 Structural adaptation with respect to self-organisation and dynamics is moderately more important than Compliance with respect to goal orientation
- 1 Structural adaptation with respect to self-organisation and dynamics and Compliance with respect to goal orientation are equally important
- 3 Compliance with respect to goal orientation is moderately more important than Structural adaptation with respect to self-organisation and dynamics
- 5 Compliance with respect to goal orientation is strongly more important than Structural adaptation with respect to self-organisation and dynamics
- 7 Compliance with respect to goal orientation is very strongly more important than Structural adaptation with respect to self-organisation and dynamics
- 9 Compliance with respect to goal orientation is extremely more important than Structural adaptation with respect to self-organisation and dynamics

72. Compare the relative importance between Structural adaptation with respect to self-organisation and dynamics and Fractal information system integration with respect to the "Integration".

Structural adaptation means appropriate modification of network structure and deployment of physical assets to facilitate integration among Basic Fractal Units (BFU) as well as fractals in the different levels. **Fractal information system integration** can be developed by fractal characteristics because each unit in fractal supply network has similar knowledge structure. Therefore, each unit has the ability to represent system procedures by using self-organisation.

Mark only one oval.

- 9 Structural adaptation is extremely more important than fractal information system integration
- 7 Structural adaptation with respect to self-organisation is very strongly more important than Fractal information system integration
- 5 Structural adaptation with respect to self-organisation is strongly more important than Fractal information system integration
- 3 Structural adaptation with respect to self-organisation is moderately more important than Fractal information system integration
- 1 Structural adaptation with respect to self-organisation and Fractal information system integration are equally important
- 3 Fractal information system integration is moderately more important than Structural adaptation with respect to self-organisation
- 5 Fractal information system integration is strongly more important than Structural adaptation with respect to self-organisation
- 7 Fractal information system integration is very strongly more important than Structural adaptation with respect to self-organisation
- 9 Fractal information system integration is extremely more important than Structural adaptation with respect to self-organisation

73. Compare the relative importance between Compliance with respect to goal orientation and Fractal information system integration with respect to the "Integration".

Compliance means adherence to established operational and administrative policies and procedures in the fractal supply network. **Fractal information system integration** can be developed by fractal characteristics because each unit in fractal supply network has similar knowledge structure. Therefore, each unit has the ability to represent system procedures by using self-organisation.

Mark only one oval.

- 9 Compliance with respect to goal orientation is extremely more important than Fractal information system integration
- 7 Compliance with respect to goal orientation is very strongly more important than Fractal information system integration
- 5 Compliance with respect to goal orientation is strongly more important than Fractal information system integration
- 3 Compliance with respect to goal orientation is moderately more important than Fractal information system integration
- 1 Compliance with respect to goal orientation and fractal information system integration are equally important
- 3 Fractal information system integration is moderately more important than Compliance with respect to goal orientation
- 5 Fractal information system integration is strongly more important than Compliance with respect to goal orientation
- 7 Fractal information system integration is very strongly more important than Compliance with respect to goal orientation
- 9 Fractal information system integration is extremely more important than Compliance with respect to goal orientation

74. Compare the relative importance between Selective distribution coverage with respect to goal orientation and Supplier selection, relationship and involvement in the fractal supply network with respect to the "Supply-oriented capability".

Selective Distribution Coverage means the ability to effectively target selective or exclusive distribution outlets within the fractal supply network. Selection and maintenance of high quality and reliable Suppliers is one of the main success keys in the supply network.

Mark only one oval.

- 9 Selective distribution coverage with respect to goal orientation is extremely more important than Supplier selection, relationship and involvement in the fractal supply network
- 7 Selective distribution coverage with respect to goal orientation is very strongly more important than Supplier selection, relationship and involvement in the fractal supply network
- 5 Selective distribution coverage with respect to goal orientation is strongly more important than Supplier selection, relationship and involvement in the fractal supply network
- 3 Selective distribution coverage with respect to goal orientation is moderately more important than Supplier selection, relationship and involvement in the fractal supply network
- 1 Selective distribution coverage with respect to goal orientation and Supplier selection, relationship and involvement in the fractal supply network are equally important
- 3 Supplier selection, relationship and involvement in the fractal supply network is moderately more important than Selective distribution coverage with respect to goal orientation
- 5 Supplier selection, relationship and involvement in the fractal supply network is strongly more important than Selective distribution coverage with respect to goal orientation
- 7 Supplier selection, relationship and involvement in the fractal supply network is very strongly more important than Selective distribution coverage with respect to goal orientation
- 9 Supplier selection, relationship and involvement in the fractal supply network is extremely more important than Selective distribution coverage with respect to goal orientation

75. Compare the relative importance between Selective distribution coverage with respect to goal orientation and Reverse logistics in the fractal supply network with respect to the "Supply-oriented capability".

Selective Distribution Coverage means the ability to effectively target selective or exclusive distribution outlets within the fractal supply network. **Reverse logistics** means all operations related to the reuse of products and materials in the fractal supply network.

Mark only one oval.

- 9 Selective distribution coverage with respect to goal orientation is extremely more important than Reverse logistics in the fractal supply network
- 7 Selective distribution coverage with respect to goal orientation is very strongly more important than Reverse logistics in the fractal supply network
- 5 Selective distribution coverage with respect to goal orientation is strongly more important than Reverse logistics in the fractal supply network
- 3 Selective distribution coverage with respect to goal orientation is moderately more important than Reverse logistics in the fractal supply network
- 1 Selective distribution coverage with respect to goal orientation and Reverse logistics in the fractal supply network are equally important
- 3 Reverse logistics in the fractal supply network is moderately more important than Selective distribution coverage with respect to goal orientation
- 5 Reverse logistics in the fractal supply network is strongly more important than Selective distribution coverage with respect to goal orientation
- 7 Reverse logistics in the fractal supply network is very strongly more important than Selective distribution coverage with respect to goal orientation
- 9 Reverse logistics in the fractal supply network is extremely more important than Selective distribution coverage with respect to goal orientation

76. Compare the relative importance between Selective distribution coverage with respect to goal orientation and Operating across different businesses and different regions with respect to the "Supply-oriented capability".

Selective Distribution Coverage means the ability to effectively target selective or exclusive distribution outlets within the fractal supply network. **Operating across different businesses and different regions** is the way that promote fractal supply network to organise by self.

Mark only one oval.

- 9 Selective distribution coverage with respect to goal orientation is extremely more important than Operating across different businesses and different regions
- 7 Selective distribution coverage with respect to goal orientation is very strongly more important than Operating across different businesses and different regions
- 5 Selective distribution coverage with respect to goal orientation is strongly more important than Operating across different businesses and different regions
- 3 Selective distribution coverage with respect to goal orientation is moderately more important than Operating across different businesses and different regions
- 1 Selective distribution coverage with respect to goal orientation and Operating across different businesses and different regions are equally important
- 3 Operating across different businesses and different regions is moderately more important than Selective distribution coverage with respect to goal orientation
- 5 Operating across different businesses and different regions is strongly more important than Selective distribution coverage with respect to goal orientation
- 7 Operating across different businesses and different regions is very strongly more important than Selective distribution coverage with respect to goal orientation
- 9 Operating across different businesses and different regions is extremely more important than Selective distribution coverage with respect to goal orientation

77. Compare the relative importance between Supplier selection, relationship and involvement in the fractal supply network and Reverse logistics in the fractal supply network with respect to the "Supply-oriented capability".

Selection and maintenance of high quality and reliable Suppliers is one of the main success keys in the supply network. **Reverse logistics** means all operations related to the reuse of products and materials in the fractal supply network.

Mark only one oval.

- 9 S Supplier selection, relationship and involvement in the fractal supply network is extremely more important than Reverse logistics in the fractal supply network
- 7 Supplier selection, relationship and involvement in the fractal supply network is very strongly more important than Reverse logistics in the fractal supply network
- 5 Supplier selection, relationship and involvement in the fractal supply network is strongly more important than Reverse logistics in the fractal supply network
- 3 Supplier selection, relationship and involvement in the fractal supply network is moderately more important than Reverse logistics in the fractal supply network
- 1 Supplier selection, relationship and involvement in the fractal supply network and Reverse logistics in the fractal supply network are equally important
- 3 Reverse logistics in the fractal supply network is moderately more important than Supplier selection, relationship and involvement in the fractal supply network
- 5 Reverse logistics in the fractal supply network is strongly more important than Supplier selection, relationship and involvement in the fractal supply network
- 7 Reverse logistics in the fractal supply network is very strongly more important than Supplier selection, relationship and involvement in the fractal supply network
- 9 Reverse logistics in the fractal supply network is extremely more important than Supplier selection, relationship and involvement in the fractal supply network

78. Compare the relative importance between Supplier selection, relationship and involvement in the fractal supply network and Operating across different businesses and different regions with respect to the "Supply-oriented capability".

Selection and maintenance of high quality and reliable Suppliers is one of the main success keys in the supply network. **Operating across different businesses and different regions** is the way that promote fractal supply network to organise by self.

Mark only one oval.

- 9 Supplier selection, relationship and involvement in the fractal supply network is extremely more important than Operating across different businesses and different regions
- 7 Supplier selection, relationship and involvement in the fractal supply network is very strongly more important than Operating across different businesses and different regions
- 5 Supplier selection, relationship and involvement in the fractal supply network is strongly more important than Operating across different businesses and different regions
- 3 Supplier selection, relationship and involvement in the fractal supply network is moderately more important than Operating across different businesses and different regions
- 1 Supplier selection, relationship and involvement in the fractal supply network and Operating across different businesses and different regions are equally important
- 3 Operating across different businesses and different regions is moderately more important than s Supplier selection, relationship and involvement in the fractal supply network
- 5 Operating across different businesses and different regions is strongly more important than Supplier selection, relationship and involvement in the fractal supply network
- 7 Operating across different businesses and different regions is very strongly more important than Supplier selection, relationship and involvement in the fractal supply network
- 9 Operating across different businesses and different regions is extremely more important than Supplier selection, relationship and involvement in the fractal supply network

79. Compare the relative importance between Reverse logistics in the fractal supply network and operating across different businesses and different regions with respect to the "Supply-oriented capability".

Reverse logistics means all operations related to the reuse of products and materials in the fractal supply network. Oper**ating across different businesses and different regions** is the way that promote fractal supply network to organise by self.

Mark only one oval.

- 9 Reverse logistics in the fractal supply network is extremely more important than Operating across different businesses and different regions
- 7 Reverse logistics in the fractal supply network is very strongly more important than Operating across different businesses and different regions
- 5 Reverse logistics in the fractal supply network is strongly more important than Operating across different businesses and different regions
- 3 Reverse logistics in the fractal supply network is moderately more important than Operating across different businesses and different regions
- 1 Reverse logistics in the fractal supply network and Operating across different businesses and different regions are equally important
- 3 Operating across different businesses and different regions is moderately more important than Reverse logistics in the fractal supply network
- 5 Operating across different businesses and different regions is strongly more important than Reverse logistics in the fractal supply network
- 7 Operating across different businesses and different regions is very strongly more important than Reverse logistics in the fractal supply network
- 9 Operating across different businesses and different regions is extremely more important than Reverse logistics in the fractal supply network

80. Compare the relative importance between Customer service focus with respect to goal orientation and Output improvement of products or services with respect to the "Customer demand-oriented capability".

Customer service focus with respect to goal orientation means each BFU provides services according to an individual-level goal and acts independently while attempting to achieve the fractal supply network's main goal. **Output improvement of products or services** is one of the three main drivers that promote fractal supply network to organise by self.

Mark only one oval.

- 9 Customer service focus with respect to goal orientation is extremely more important than Output improvement of products or services
- 7 Customer service focus with respect to goal orientation is very strongly more important than Output improvement of products or services
- 5 Customer service focus with respect to goal orientation is strongly more important than Output improvement of products or services
- 3 Customer service focus with respect to goal orientation is moderately more important than Output improvement of products or services
- 1 Customer service focus with respect to goal orientation and Output improvement of products or services are equally important
- 3 Output improvement of products or services is moderately more important than Customer service focus with respect to goal orientation
- 5 Output improvement of products or services is strongly more important than Customer service focus with respect to goal orientation
- 7 Output improvement of products or services is very strongly more important than Customer service focus with respect to goal orientation
- 9 Output improvement of products or services is extremely more important than Customer service focus with respect to goal orientation

81. Compare the relative importance between Customer service focus with respect to goal orientation and Product or service reconfiguration for next lifecycle with respect to the "Customer demand-oriented capability".

Customer service focus with respect to goal orientation means each Basic Fractal Units (BFU) provides services according to an individual-level goal and acts independently while attempting to achieve the fractal supply network's main goal. **Product or service reconfiguration for next lifecycle** is one of the three main drivers that promote fractal supply network to organize by self.

Mark only one oval.

- 9 Customer service focus with respect to goal orientation is extremely more important than Product or service reconfiguration for next lifecycle
- 7 Customer service focus with respect to goal orientation is very strongly more important than Product or service reconfiguration for next lifecycle
- 5 Customer service focus with respect to goal orientation is strongly more important than Product or service reconfiguration for next lifecycle
- 3 Customer service focus with respect to goal orientation is moderately more important than Product or service reconfiguration for next lifecycle
- 1 Customer service focus with respect to goal orientation and Product or service reconfiguration for next lifecycle are equally important
- 3 Product or service reconfiguration for next lifecycle is moderately more important than Customer service focus with respect to goal orientation
- 5 Product or service reconfiguration for next lifecycle is strongly more important than Customer service focus with respect to goal orientation
- 7 Product or service reconfiguration for next lifecycle is very strongly more important than Customer service focus with respect to goal orientation
- 9 Product or service reconfiguration for next lifecycle is extremely more important than Customer service focus with respect to goal orientation

82. Compare the relative importance between Customer service focus with respect to goal orientation and Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation with respect to the "Customer demand-oriented capability".

Customer service focus with respect to goal orientation means each Basic Fractal Units (BFU) provides services according to an individual-level goal and acts independently while attempting to achieve the fractal supply network's main goal. **The ability to segment customers** based on specific logistics requirements with respect to self-optimisation is an important aspect of customer focus capability.

Mark only one oval.

- 9 Customer service focus with respect to goal orientation is extremely more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 7 Customer service focus with respect to goal orientation is very strongly more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 5 Customer service focus with respect to goal orientation is strongly more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 3 Customer service focus with respect to goal orientation is moderately more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 1 Customer service focus with respect to goal orientation and Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation are equally important
- 3 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is moderately more important than Customer service focus with respect to goal orientation
- 5 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is strongly more important than Customer service focus with respect to goal orientation
- 7 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is very strongly more important than Customer service focus with respect to goal orientation
- 9 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is extremely more important than Customer service focus with respect to goal orientation

83. Compare the relative importance between Output improvement of products or services and Product or service reconfiguration for next lifecycle with respect to the "Customer demand-oriented capability".

Output improvement of products or services is one of the three main drivers that promote fractal supply network to organise by self. **Product or service reconfiguration for next lifecycle** is one of the three main drivers that promote fractal supply network to organize by self.

Mark only one oval.

- 9 Output improvement of products or services is extremely more important than Product or service reconfiguration for next lifecycle
- 7 Output improvement of products or services is very strongly more important than Product or service reconfiguration for next lifecycle
- 5 Output improvement of products or services is strongly more important than Product or service reconfiguration for next lifecycle
- 3 Output improvement of products or services is moderately more important than Product or service reconfiguration for next lifecycle
- 1 Output improvement of products or services and Product or service reconfiguration for next lifecycle are equally important
- 3 Product or service reconfiguration for next lifecycle is moderately more important than Output improvement of products or services
- 5 Product or service reconfiguration for next lifecycle is strongly more important than Output improvement of products or services
- 7 Product or service reconfiguration for next lifecycle is very strongly more important than Output improvement of products or services
- 9 Product or service reconfiguration for next lifecycle is extremely more important than Output improvement of products or services

84. Compare the relative importance between Output improvement of products or services and Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation with respect to the "Customer demand-oriented capability".

Output improvement of products or services is one of the three main drivers that promote fractal supply network to organise by self. **The ability to segment customers** based on specific logistics requirements with respect to self-optimisation is an important aspect of customer focus capability. *Mark only one oval.*

- 9 Output improvement of products or services is extremely more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 7 Output improvement of products or services is very strongly more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 5 Output improvement of products or services is strongly more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 3 Output improvement of products or services is moderately more important than Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation
- 1 Output improvement of products or services and Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation are equally important
- 3 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is moderately more important than Output improvement of products or services
- 5 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is strongly more important than Output improvement of products or services
- 7 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is very strongly more important than Output improvement of products or services
- 9 Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation is extremely more important than Output improvement of products or services

85. Compare the relative importance between Product or service reconfiguration for next lifecycle and Use appropriate customer segmentation strategies in terms of logistics requirements with respect to self-optimisation with respect to the "Customer demand-oriented capability".

Product or service reconfiguration for next lifecycle is one of the three main drivers that promote fractal supply network to organize by self. **The ability to segment** customers based on specific logistics requirements with respect to self-optimisation is an important aspect of customer focus capability.

Mark only one oval.

- 9 Product or service reconfiguration for next lifecycle is extremely more important than Use appropriate customer segmentation strategies in terms of logistics requirements
- 7 Product or service reconfiguration for next lifecycle is very strongly more important than Use appropriate customer segmentation strategies in terms of logistics requirements
- 5 Product or service reconfiguration for next lifecycle is strongly more important than Use appropriate customer segmentation strategies in terms of logistics requirements
- 3 Product or service reconfiguration for next lifecycle is moderately more important than Use appropriate customer segmentation strategies in terms of logistics requirements
- 1 Product or service reconfiguration for next lifecycle and Use appropriate customer segmentation strategies in terms of logistics requirements are equally important
- 3 Use appropriate customer segmentation strategies in terms of logistics requirements is moderately more important than Product or service reconfiguration for next lifecycle
- 5 Use appropriate customer segmentation strategies in terms of logistics requirements is strongly more important than Product or service reconfiguration for next lifecycle
- 7 Use appropriate customer segmentation strategies in terms of logistics requirements is very strongly more important than Product or service reconfiguration for next lifecycle
- 9 Use appropriate customer segmentation strategies in terms of logistics requirements is extremely more important than Product or service reconfiguration for next lifecycle

86. Compare the relative importance between Use a fractal paradigm in information systems development and Development of appropriate information technology with respect to the "Information exchange capability".

The fractal paradigm can be applied at both business process system and software system. In fractal paradigm each unit present information as service for other units to gain targets. Therefore, this ability raises information flow as well as storage among fractal units. **Development of appropriate information technology** increase collaboration Characteristics between fractals. *Mark only one oval.*

- 9 Use a fractal paradigm in information systems development is extremely more important than Development of appropriate information technology
- 7 Use a fractal paradigm in information systems development is very strongly more important than Development of appropriate information technology
- 5 Use a fractal paradigm in information systems development is strongly more important than Development of appropriate information technology
- 3 Use a fractal paradigm in information systems development is moderately more important than Development of appropriate information technology
- 1 Use a fractal paradigm in information systems development and Development of appropriate information technology are equally important
- 3 Development of appropriate information technology is moderately more important than Use a fractal paradigm in information systems development
- 5 Development of appropriate information technology is strongly more important than Use a fractal paradigm in information systems development
- 7 Development of appropriate information technology is very strongly more important than Use a fractal paradigm in information systems development
- 9 Development of appropriate information technology is extremely more important than Use a fractal paradigm in information systems development

87. Compare the relative importance between Use a fractal paradigm in information systems development and Information sharing with respect to the "Information exchange capability".

The fractal paradigm can be applied at both business process system and software system. In fractal paradigm each unit present information as service for other units to gain targets. Therefore, this ability raises information flow as well as storage among fractal units. **Uses information** from Basic Fractal Units (BFU) as well as fractals in the different levels reduced the negative effects of uncertainty in the fractal environment such as high inventory levels and wrong demand forecasts and defective orders.

Mark only one oval.

- 9 Use a fractal paradigm in information systems development is extremely more important than information sharing
- 7 Use a fractal paradigm in information systems development is very strongly more important than information sharing
- 5 Use a fractal paradigm in information systems development is strongly more important than information sharing
- 3 Use a fractal paradigm in information systems development is moderately more important than information sharing
- 1 Use a fractal paradigm in information systems development and information sharing are equally important
- 3 Information sharing is moderately more important than Use a fractal paradigm in information systems development
- 5 Information sharing is strongly more important than Use a fractal paradigm in information systems development
- 7 Information sharing is very strongly more important than Use a fractal paradigm in information systems development
- 9 Information sharing is extremely more important than Use a fractal paradigm in information systems development

88. Compare the relative importance between Use a fractal paradigm in information systems development and Connectivity with respect to the "Information exchange capability".

The fractal paradigm can be applied at both business process system and software system. In fractal paradigm each unit present information as service for other units to gain targets. Therefore, this ability raises information flow as well as storage among fractal units. **In fractal supply network** due to decrease of complexity, connectivity among fractal supply networks units increase flexibility, decrease complication of work system and makes easier to control system process activities.

Mark only one oval.

- 9 Use a fractal paradigm in information systems development is extremely more important than Connectivity
- 7 Use a fractal paradigm in information systems development is very strongly more important than Connectivity
- 5 Use a fractal paradigm in information systems development is strongly more important than connectivity
- 3 Use a fractal paradigm in information systems development is moderately more important than Connectivity
- 1 Use a fractal paradigm in information systems development and Connectivity are equally important
- 3 Connectivity is moderately more important than Use a fractal paradigm in information systems development
- 5 Connectivity is strongly more important than Use a fractal paradigm in information systems development
- 7 Connectivity is very strongly more important than Use a fractal paradigm in information systems development
- 9 Connectivity is extremely more important than Use a fractal paradigm in information systems development

89. **Compare the relative importance between Development of appropriate information technology and Information sharing with respect to the "Information exchange capability".**

Development of appropriate information technology increase collaboration Characteristics between fractals. **Uses information** from Basic Fractal Units (BFU) as well as fractals in the different levels reduced the negative effects of uncertainty in the fractal environment such as high inventory levels and wrong demand forecasts and defective orders.

Mark only one oval.

- 9 Development of appropriate information technology is extremely more important than Information sharing
- 7 Development of appropriate information technology is very strongly more important than Information sharing
- 5 Development of appropriate information technology is strongly more important than Information sharing
- 3 Development of appropriate information technology is moderately more important than Information sharing
- 1 Development of appropriate information technology and Information sharing are equally important
- 3 Information sharing is moderately more important than Development of appropriate information technology
- 5 Information sharing is strongly more important than Development of appropriate information technology
- 7 Information sharing is very strongly more important than Development of appropriate information technology
- 9 Information sharing is extremely more important than Development of appropriate information technology

90. **Compare the relative importance between Development of appropriate information technology and Connectivity with respect to the "Information exchange capability".**

Development of appropriate information technology increase collaboration Characteristics between fractals. **In fractal supply network** due to decrease of complexity, connectivity among fractal supply networks units increase flexibility, decrease complication of work system and makes easier to control system process activities.

Mark only one oval

- 9 Development of appropriate information technology is extremely more important than Connectivity
- 7 Development of appropriate information technology is very strongly more important than Connectivity
- 5 Development of appropriate information technology is strongly more important than Connectivity
- 3 Development of appropriate information technology is moderately more important than Connectivity
- 1 Development of appropriate information technology and Connectivity are equally important
- 3 Connectivity is moderately more important than Development of appropriate information technology
- 5 Connectivity is strongly more important than Development of appropriate information technology
- 7 Connectivity is very strongly more important than Development of appropriate information technology
- 9 Connectivity is extremely more important than Development of appropriate information technology

91. Compare the relative importance between Information sharing and Connectivity with respect to the "Information exchange capability".

Uses information from Basic Fractal Units (BFU) as well as fractals in the different levels reduced the negative effects of uncertainty in the fractal environment such as high inventory levels and wrong demand forecasts and defective orders. **In fractal supply network** due to decrease of complexity, connectivity among fractal supply networks units increase flexibility, decrease complication of work system and makes easier to control system process activities.

Mark only one oval.

- 9 Information sharing is extremely more important than Connectivity
- 7 Information sharing is very strongly more important than Connectivity
- 5 Information sharing is strongly more important than Connectivity
- 3 Information sharing is moderately more important than Connectivity
- 1 Information sharing and Connectivity are equally important
- 3 Connectivity is moderately more important than Information sharing
- 5 Connectivity is strongly more important than Information sharing
- 7 Connectivity is very strongly more important than Information sharing
- 9 Connectivity is extremely more important than Information sharing

92. Compare the relative importance between logistics postponement and speculation and inventory cost with respect to the "Time management and logistics cost capability".

Logistics postponement and speculation mean involve delaying the forward movement of goods as long as possible and storing goods at central locations within the fractal supply network. **Inventory cost** includes costs of raw material, finished goods, and pipeline in the fractal supply network.

Mark only one oval.

- 9 Logistics postponement and speculation is extremely more important than Inventory cost
- 7 Logistics postponement and speculation is very strongly more important than inventory cost
- 5 Logistics postponement and speculation is strongly more important than Inventory cost
- 3 Logistics postponement and speculation is moderately more important than Inventory cost
- 1 Logistics postponement and speculation and Inventory cost are equally important
- 3 Inventory cost is moderately more important than Logistics postponement and speculation
- 5 Inventory cost is strongly more important than Logistics postponement and speculation
- 7 Inventory cost is very strongly important than Logistics postponement and speculation
- 9 Inventory cost is extremely more important than Logistics postponement and speculation

93. **Compare the relative importance between Logistics postponement and speculation and Low total cost distribution with respect to the "Time management and logistics cost capability"**.

Logistics postponement and speculation mean involve delaying the forward movement of goods as long as possible and storing goods at central locations within the fractal supply network. **Low total cost distribution** is the ability to minimize the total cost of the distribution in the fractal supply network.

Mark only one oval.

- 9 Logistics postponement and speculation is extremely more important than Low total cost distribution
- 7 Logistics postponement and speculation is very strongly more important than Low total cost distribution
- 5 Logistics postponement and speculation is strongly more important than Low total cost distribution
- 3 Logistics postponement and speculation is moderately more important than Low total cost distribution
- 1 Logistics postponement and speculation and Low total cost distribution are equally important
- 3 Low total cost distribution is moderately more important than Logistics postponement and speculation
- 5 Low total cost distribution is strongly more important than Logistics postponement and speculation
- 7 Low total cost distribution is very strongly important than Logistics postponement and speculation
- 9 Low total cost distribution is extremely more important than Logistics postponement and speculation

94. **Compare the relative importance between Logistics postponement and speculation and Responsiveness to customer demand fluctuations with respect to the "Time management and logistics cost capability".**

Logistics postponement and speculation mean involve delaying the forward movement of goods as long as possible and storing goods at central locations within the fractal supply network. **Fractal supply network** try to optimize the system through local optimization rather than global optimization since local optimization reduces the computational burden and time to respond faster to customer demand fluctuations.

Mark only one oval.

- 9 Logistics postponement and speculation is extremely more important than Responsiveness to customer demand fluctuations
- 7 Logistics postponement and speculation is very strongly more important than Responsiveness to customer demand fluctuations
- 5 Logistics postponement and speculation is strongly more important than Responsiveness to customer demand fluctuations
- 3 Logistics postponement and speculation is moderately more important than Responsiveness to customer demand fluctuations
- 1 Logistics postponement and speculation and Responsiveness to customer demand fluctuations are equally important
- 3 Responsiveness to customer demand fluctuations is moderately more important than Logistics postponement and speculation
- 5 Responsiveness to customer demand fluctuations is strongly more important than Logistics postponement and speculation
- 7 Responsiveness to customer demand fluctuations is very strongly important than Logistics postponement and speculation
- 9 Responsiveness to customer demand fluctuations is extremely more important than Logistics postponement and speculation

95. Compare the relative importance between Inventory cost and Low total cost distribution with respect to the "Time management and logistics cost capability".

Inventory cost includes costs of raw material, finished goods, and pipeline in the fractal supply network. **Low total cost distribution** is the ability to minimize the total cost of the distribution in the fractal supply network.

Mark only one oval.

- 9 Inventory cost is extremely more important than Low total cost distribution
- 7 Inventory cost is very strongly more important than Low total cost distribution
- 5 Inventory cost is strongly more important than Low total cost distribution
- 3 Inventory cost is moderately more important than Low total cost distribution
- 1 Inventory cost and Low total cost distribution are equally important
- 3 Low total cost distribution is moderately more important than Inventory cost
- 5 Low total cost distribution is strongly more important than Inventory cost
- 7 Low total cost distribution is very strongly important than Inventory cost
- 9 Low total cost distribution is extremely more important than Inventory cost

96. Compare the relative importance between Inventory cost and Responsiveness to customer demand fluctuations with respect to the "Time management and logistics cost capability".

Inventory cost includes costs of raw material, finished goods, and pipeline in the fractal supply network. Fr**actal supply network** try to optimize the system through local optimization rather than global optimization since local optimization reduces the computational burden and time to respond faster to customer demand fluctuations.

Mark only one oval.

- 9 Inventory cost is extremely more important than Responsiveness to customer demand fluctuations
- 7 Inventory cost is very strongly more important than Responsiveness to customer demand fluctuations
- 5 Inventory cost is strongly more important than Responsiveness to customer demand fluctuations
- 3 Inventory cost is moderately more important than Responsiveness to customer demand fluctuations
- 1 Inventory cost and Responsiveness to customer demand fluctuations are equally important
- 3 Responsiveness to customer demand fluctuations is moderately more important than Inventory cost
- 5 Responsiveness to customer demand fluctuations is strongly more important than Inventory cost
- 7 Responsiveness to customer demand fluctuations is very strongly important than Inventory cost
- 9 Responsiveness to customer demand fluctuations is extremely more important than Inventory cost

97. **Compare the relative importance between Low total cost distribution and Responsiveness to customer demand fluctuations with respect to the "Time management and logistics cost capability".**

Low total cost distribution is the ability to minimize the total cost of the distribution in the fractal supply network. **Fractal supply network** try to optimize the system through local optimization rather than global optimization since local optimization reduces the computational burden and time to respond faster to customer demand fluctuations.

Mark only one oval.

- 9 Low total cost distribution is extremely more important than Responsiveness to customer demand fluctuations
- 7 Low total cost distribution is very strongly more important than Responsiveness to customer demand fluctuations
- 5 Low total cost distribution is strongly more important than Responsiveness to customer demand fluctuations
- 3 Low total cost distribution is moderately more important than Responsiveness to customer demand fluctuations
- 1 Low total cost distribution and Responsiveness to customer demand fluctuations are equally important
- 3 Responsiveness to customer demand fluctuations is moderately more important than Low total cost distribution
- 5 Responsiveness to customer demand fluctuations is strongly more important than Low total cost distribution
- 7 Responsiveness to customer demand fluctuations is very strongly important than Low total cost distribution
- 9 Responsiveness to customer demand fluctuations is extremely more important than Low total cost distribution

SECTION B

98. **Are there any more criteria and sub-criteria should have been considered and need to include, please provide details?**

....
....
....
....

99. **Are there any more criteria and sub-criteria should have been considered and need to include, please provide details?**

....
....
....

Appendix 2- MATLAB Code

Create models

```
function model=CreatModel(I,J)
%    I= Number of Customers
%    J= Number of vehicle
    r=[]; % Customer Demand extracted from Guru software
    c=3000; %Vehicle capacity
    vw=3000; % Vehicle tare weigh
    x,y= %coordinates of existing customer extracted from Guru
software
    x0,y0= %coordinates of greenfield sites extracted from Guru
software
    d=zeros(I,I);
    d0=zeros(1,I);
    for i=1:I
        for i2= i+1:I

d(i,i2)=distdim(distance(x(i),y(i),x(i2),y(i2)),'deg','kilometers');
            d(i2,i)=d(i,i2); % Distance among customers
        end

d0(i)=distdim(distance(x0,y0,x(i),y(i)),'deg','kilometers');% Distance
from greenfield sites to customers
    end
    model.I=I;
    model.J=J;
    model.r=r;
    model.x=x;
    model.x0=x0;
    model.y0=y0;
    model.y=y;
    model.d=d;
    model.d0=d0;
    model.vw=vw;
    model.c=c;
end
```

Create and Save model

```
function CreatAndSaveModel()

    I=[];
    J=[];
    nModel=numel(I);
    for k=1:nModel
        model=CreatRandomModel(I(k),J(k));

        ModelName=['vrp_' num2str(model.I) 'x' num2str(model.J)];

       save (ModelName, 'model');
    end

end
```

Create initial Solution

```
function q=CreateRandomSolution(model)

 I=model.I;
 J=model.J;
 q=randperm(I+J-1);
end
```

Create final solution

```
 function sol=CO2C(q,model)
     I=model.I;
     J=model.J;
     d=model.d;
     d0=model.d0;
     r=model.r;
     c=model.c;
     vw=model.vw;
     DC=0;
     CH=0;
     X=q;
     a=find(X>I);
     L=cell(J,1);% L= Vehicle
     for j=1:J-1
         L{j}=unique(X(1:a(1)-1),'stable');
         X(1:a(1))=[];
         a=find(X>I);
     end
     L{j+1}=unique(X,'stable');

     D=zeros(J,1); % D= vehicle Milage
     C=zeros(J,1); % C= vehicle CO2 emission
     alpha_c=0.0005442; % Vehicle CO2 emission rate
     S=zeros(1,J); % S= Output weight from the warehouse by Vehicle

     for j=1:J
         L{j}=q(From(j):To(j));
         if ~isempty(L{j})
             D(j)=d0(L{j}(1));
             for k=1:numel(L{j})-1
                 D(j)=D(j)+d(L{j}(k),L{j}(k+1));
             end
             D(j)=D(j)+d0(L{j}(end));
         end
     end

     for j=1:J
         if ~isempty(L{j})
            last_costm=L{j}(end);
             s(j)=0;
             for ii=1:length(L{j})
                 s(j)=s(j)+r(L{j}(ii));
             end
              sh=min(s(j),c);
             C(j)=((vw+sh)*alpha_c)*d0(L{j}(1));
             sh=sh-r(L{j}(1));
             r(L{j}(1))=0;
            for k=2:numel(L{j})
                DC=DC+max(Ms-sh,0); % Vehicle Weight of shipments on
board constraint
                %Ms = Minimum shipment weight that must be on the kth
vehicle for the length of each route during its servic
                 if sh>=Ms
                      if sh>=r(L{j}(k))
                          sh=sh-r(L{j}(k));
                          r(L{j}(k))=0;
```

```
else
                          r(L{j}(k))=r(L{j}(k))-sh;
                          sh=0;
                          last_costm=L{j}(k);
                      end
                 end
           C(j)=C(j)+((vw+sh)*alpha_c)*d(L{j}(k-1),L{j}(k));
            end
             C(j)=C(j)+(vw*alpha_c)*d0(last_costm);

         end
                  ucap(j)=sum(r(L{j})); % Vehicle used capacity
                  CH=CH+max(ucap(j)-c,0);% Vehicle capacity constraint

          rn=nonzeros(r);% rn= Remaining customer demand
          rr=find(r==0);
          A=d;
          A(rr,:)=[];
          A(:,rr)=[];
          A0=d0;
          A0(:,rr)=[];
          In=numel(rn); %In= customers which thier demand are not
completed yet
          Jn=numel(rn);% rn= Remaining number of vehicle

          % the above loops are repeated to satisfy the entire
customer demand
end
     sol.L=L;
     sol.C=C;
     sol.TotalC=sum(C);
     sol.ucap=ucap;
     sol.CH=CH;
     sol.r=r;
     sol.D=D;
     sol.TotalD=sum(D);
     sol.DC=DC;
     sol.RS=RS;
     sol.c=c;
     sol.IsFeasible=(CH==0);
     sol.IsFeasible=(DC==0);
     sol.rn=rn;
     sol.In=In;
     sol.Jn=Jn;
     sol.vw=vw;
     sol.A=A;
     sol.rr=rr;
     sol.A0=A0;
 end
```

CO_2 emission function

```
function [z sol]=MyCO2(q,model)
    global NFE;
    NFE=NFE+1;
    sol=CO2C(q,model);
    z1=sol.TotalC;
    z=z1+sol.CH+sol.DC;
end
```

Plot Solution

```
function PlotSolution(sol,model)
    J=model.J;
    x=model.x;
    y=model.y;
    x0=model.x0;
    y0=model.y0;
    L=sol.L;
    Colors=hsv(J);
    for j=1:J
        if isempty(L{j})
            continue;
        end
        X=[x0 x(L{j}) x0];
        Y=[y0 y(L{j}) y0];
        Color=0.8*Colors(j,:);
        plot(X,Y,'-O',...
            'Color',Color,...
            'LineWidth',2,...
            'MarkerSize',10,...
            'MarkerFaceColor','white');
        hold on;
    end
     plot(x0,y0,'ks',...
    'LineWidth',2,...
    'MarkerSize',18,...
    'MarkerFaceColor','yellow');
    hold off;
end
```

Create Neighbour

```
function qnew=CreateNeighbor(q)
   m=randi([1 3]);
      switch m
       case 1
           % Do Swap
           qnew=Swap(q);
       case 2
           % Do Reversion
           qnew=Reversion(q);
       case 3
           % Do Insertion
           qnew=Insertion(q);
      end
end
function qnew=Swap(q)

   n=numel(q);
   i=randsample(n,2);
   i1=i(1);
   i2=i(2);
   qnew=q;
   qnew([i1 i2])=q([i2 i1]);
end
function qnew=Reversion(q)
   n=numel(q);
   i=randsample(n,2);
   i1=min(i(1),i(2));
   i2=max(i(1),i(2));
   qnew=q;
   qnew(i1:i2)=q(i2:-1:i1);
end
function qnew=Insertion(q)
   n=numel(q);
   i=randsample(n,2);
   i1=i(1);
   i2=i(2);
   if i1<i2
       qnew=[q(1:i1-1) q(i1+1:i2) q(i1) q(i2+1:end)];
   else
       qnew=[q(1:i2) q(i1) q(i2+1:i1-1) q(i1+1:end)];
   end

end
```

Select Model

```
function model=SelectModel()
     [FileName, FilePath]=uigetfile({'*.mat','MAT Files (*.m)';
'*.*','All Files(*.*)'
              '*.*','AllFiles (*.*)'},'Select Model ...');
      if FileName==0
         model=[];
         return;
      end
      FullFileName=[FilePath FileName];
      data=load(FullFileName);
      model=data.model;
end
```

```
% Create simulated annealing
clc;
clear;
close all;
global NFE;
NFE=0;
```

Problem Definition

```
model=SelectModel();        % Select Model of the Problem
CO2Function=@(q) MyCO2(q,model);       % CO2 Function
```

SA Parameters

```
MaxIt=5000;      % Maximum Number of Iterations
MaxIt2=100 ;      % Maximum Number of Inner Iterations
T0=100;          % Initial Temperature
alpha=0.99;     % Temperature Damping Rate
```

Initialization

```
% Create Initial Solution
x.Position=CreateRandomSolution(model);
[x.CO2 x.Sol]=CO2Function(x.Position);
% Update Best Solution Ever Found
BestSol=x;
% Array to Hold Best CO2 Values
BestCO2=zeros(MaxIt,1);
% Array to Hold NFEs
nfe=zeros(MaxIt,1);
% Set Initial Temperature
T=T0;
```

SA Main Loop

```
for it=1:MaxIt
    for it2=1:MaxIt2
        % Create Neighbor
        xnew.Position=CreateNeighbor(x.Position);
        [xnew.CO2 xnew.Sol]=CO2Function(xnew.Position);
        if xnew.CO2<=x.CO2
            % xnew is better, so it is accepted
            x=xnew;
        else
            % xnew is not better, so it is accepted conditionally
            delta=xnew.CO2-x.CO2;
            p=exp(-delta/T);
            if rand<=p
                x=xnew;
            end
        end
        % Update Best Solution
        if x.CO2<=BestSol.CO2
            BestSol=x;
        end
    end
    % Store Best CO2
    BestCO2(it)=BestSol.CO2;
    if BestSol.Sol.IsFeasible
        FLAG=' *';
    else
        FLAG='**';
    end
    % Store NFE
    nfe(it)=NFE;
    % Display Iteration Information
    disp(['Iteration ' num2str(it) ': Best CO2 = '
num2str(BestCO2(it)) FLAG ]);
    % Reduce Temperature
    T=alpha*T;
    %Plot Solution
    figure(1);
    PlotSolution(BestSol.Sol,model);
    pause(0.01);

end
```

Results

```
figure;

plot(nfe,BestCO2,'LineWidth',2);
xlabel('NFE');
ylabel('Best CO2');
```